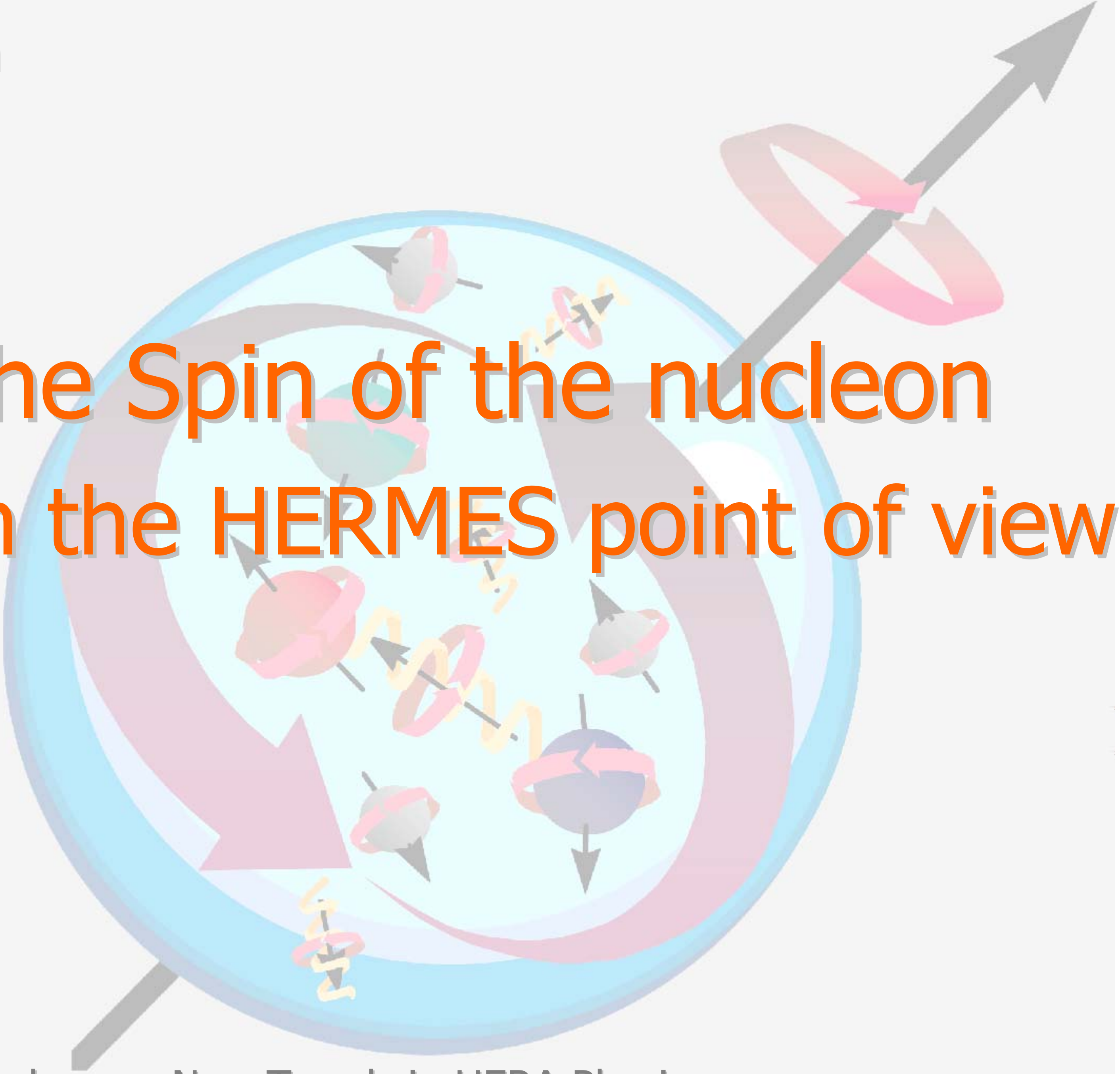
Delia Hasch

INFN Frascati

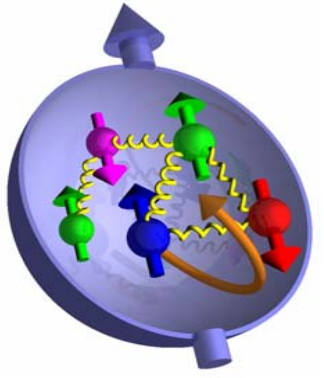


the Spin of the nucleon -from the HERMES point of view-

Ringberg workshop on New Trends in HERA Physics, Ringberg Castle, October 5-10, 2008

HERa MEasurement of Spin

$$\frac{s_z^N}{\hbar} = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_z^q + \Delta G + L_z^g$$



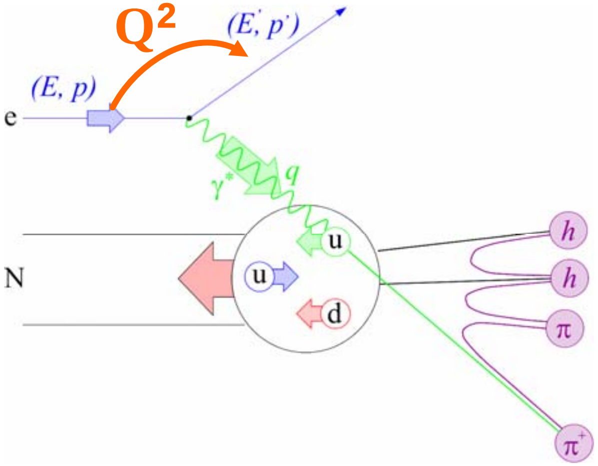
outline:

- prerequisites
- polarisation of quarks: $\Delta\Sigma = \Delta u_v + \Delta d_v + \Delta q_s$
- polarisation of gluons: ΔG

new developments

- hunting for the OAM $L_{q,g}$ → **talk by M. Düren**
- transverse spin phenomena → **talk by U. D’Alesio**

polarised deep-inelastic scattering



$$Q^2 = -q^2 \overset{\text{lab}}{=} 2EE'(1\text{-}\cos\theta)$$

$$x \overset{\text{lab}}{=} \frac{Q^2}{2M\nu}, \qquad x \in [0,1] \qquad \nu \overset{\text{lab}}{=} E - E'$$

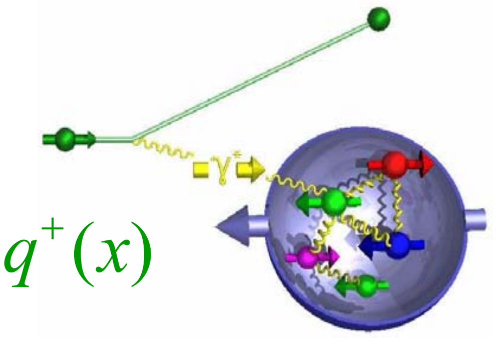
$$z \overset{\text{lab}}{=} \frac{E_h}{\nu},$$

factorisation:

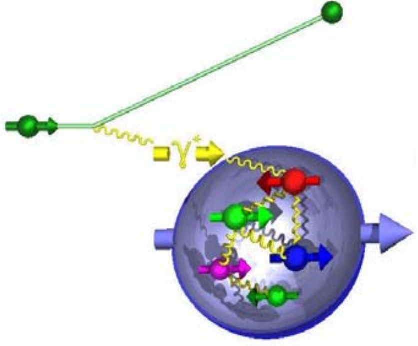
$$\sigma^h_{DIS} \propto \sum_f \hat{\sigma}_{part} \otimes pdf(x) \otimes frag^{q,g\to h}(z)$$

$$\Downarrow$$

$$\Delta q(x) = q^+(x) \ominus q^-(x)$$



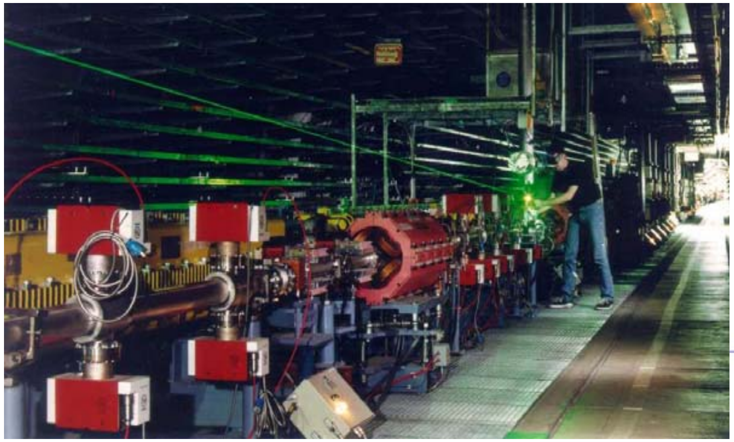
$q^+(x)$



$q^-(x)$

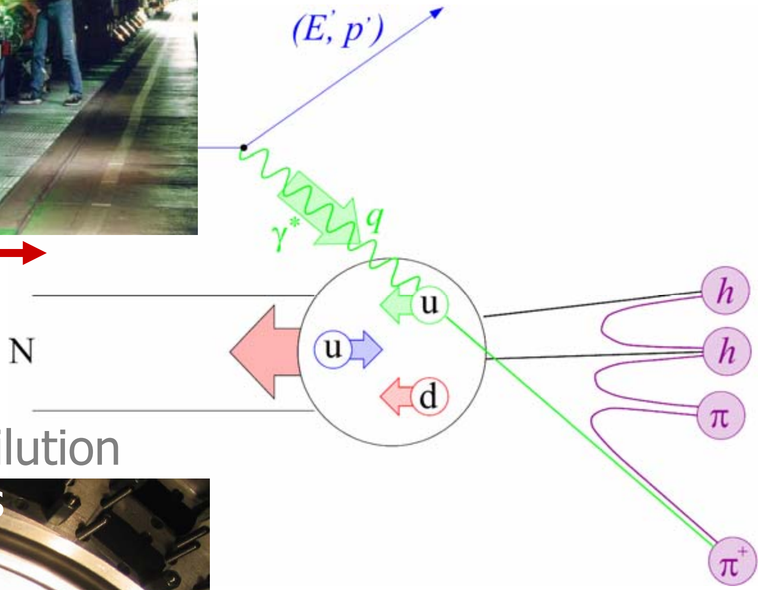
experimental prerequisites

-the 2nd generation-



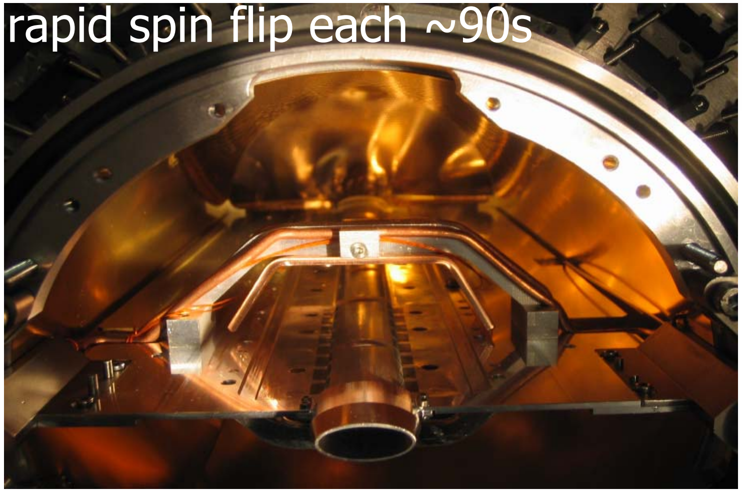
HERA 27.5 GeV (e+/e-)→

$\langle P_b \rangle \sim 53 \pm 2.5$ %



storage cell target: no dilution

rapid spin flip each ~90s



$^1H^{\rightarrow}$ $\langle |P_t| \rangle \sim 85\%$

$^2H^{\rightarrow}$ $\langle |P_t| \rangle \sim 84\%$

$^1H^{\uparrow}$ $\langle |P_t| \rangle \sim 74\%$

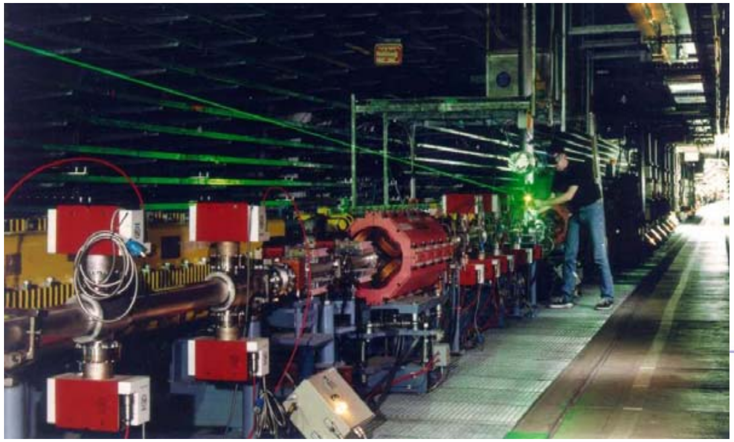
$$\delta\sigma \propto \frac{1}{\boxed{P_b P_t f}} \cdot \frac{1}{\sqrt{N}}$$

f: target dilution factor

f=1 gas targets, f~0.02 solid targets

experimental prerequisites

-the 2nd generation-



HERA 27.5 GeV $\overrightarrow{(e+/e-)}$

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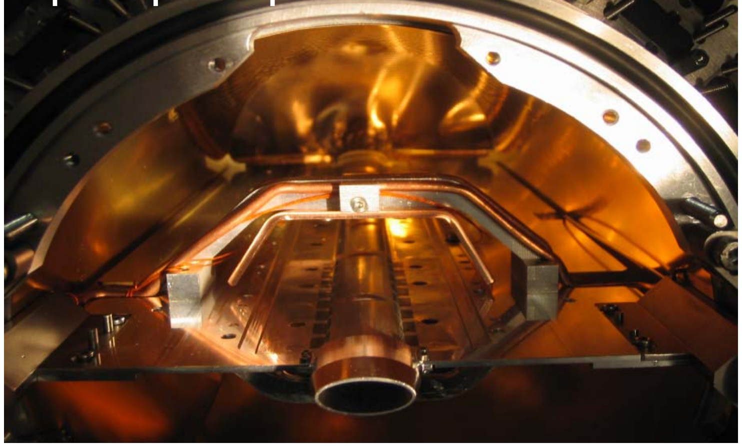

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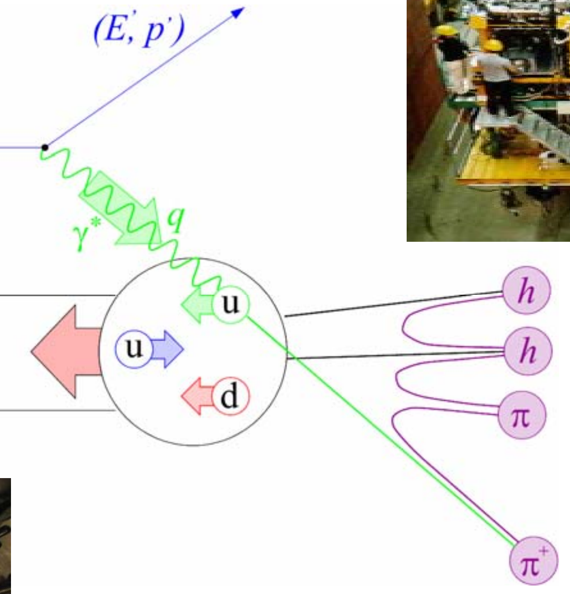
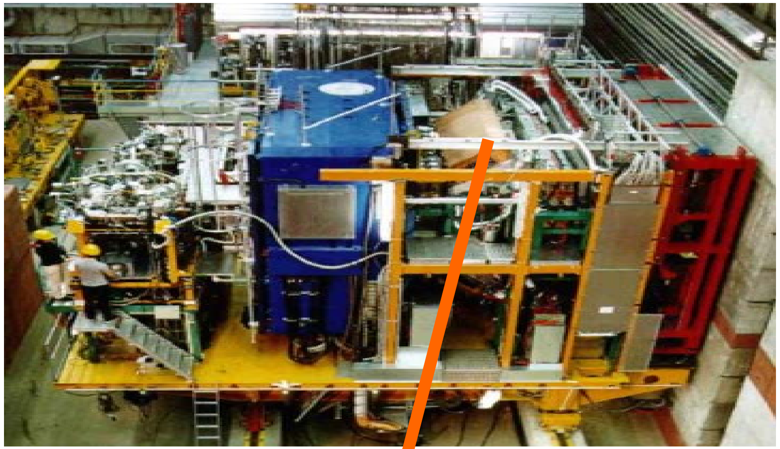
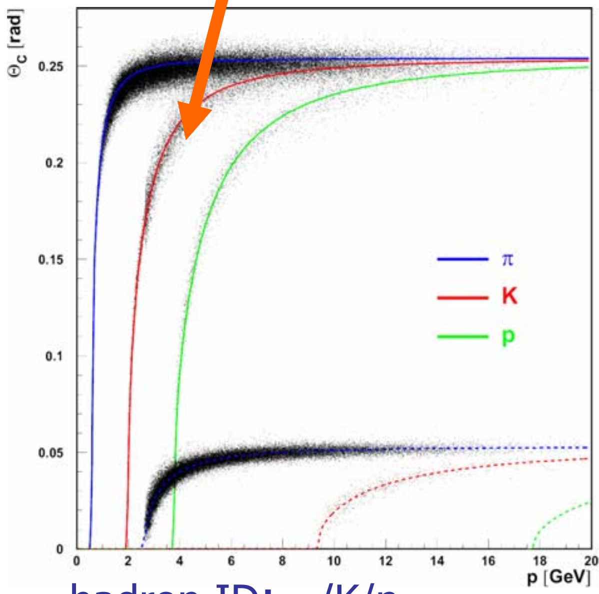




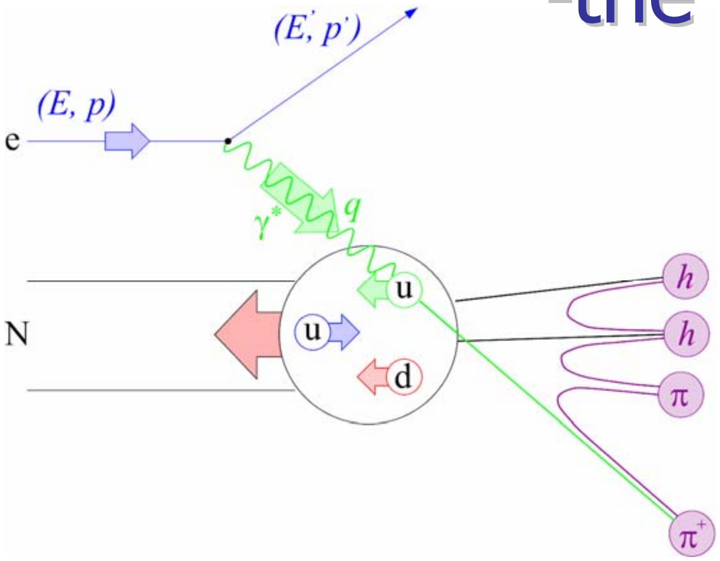


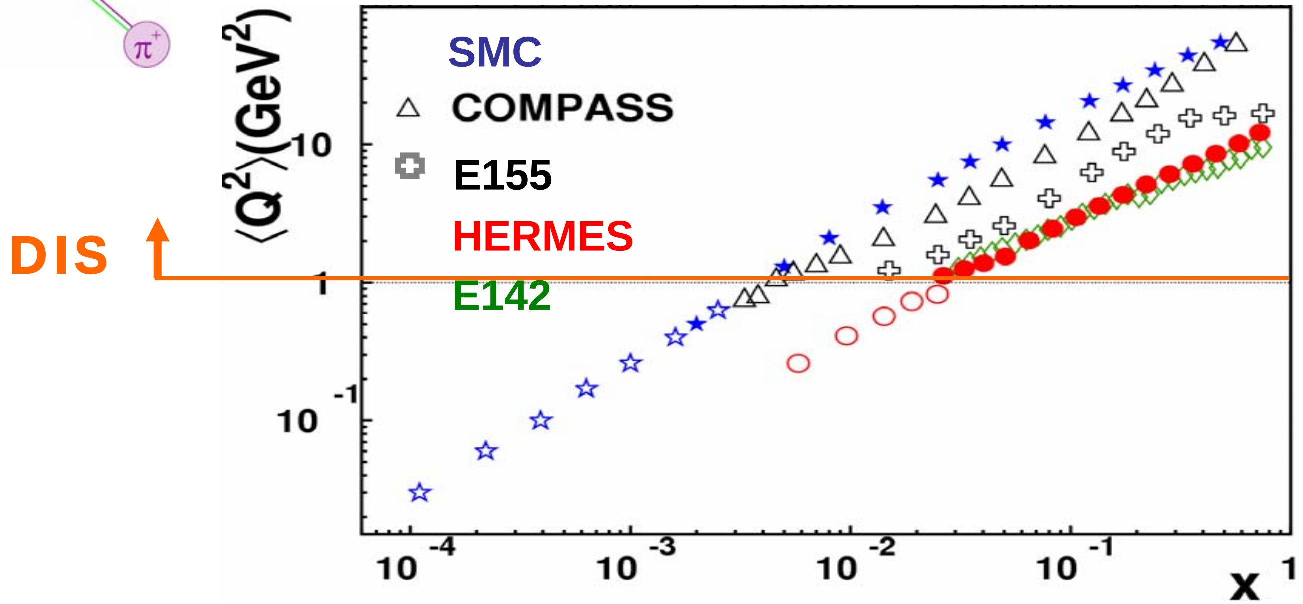
hadron ID: π/K/p

$2 < E_h < 15$ GeV

experimental prerequisites

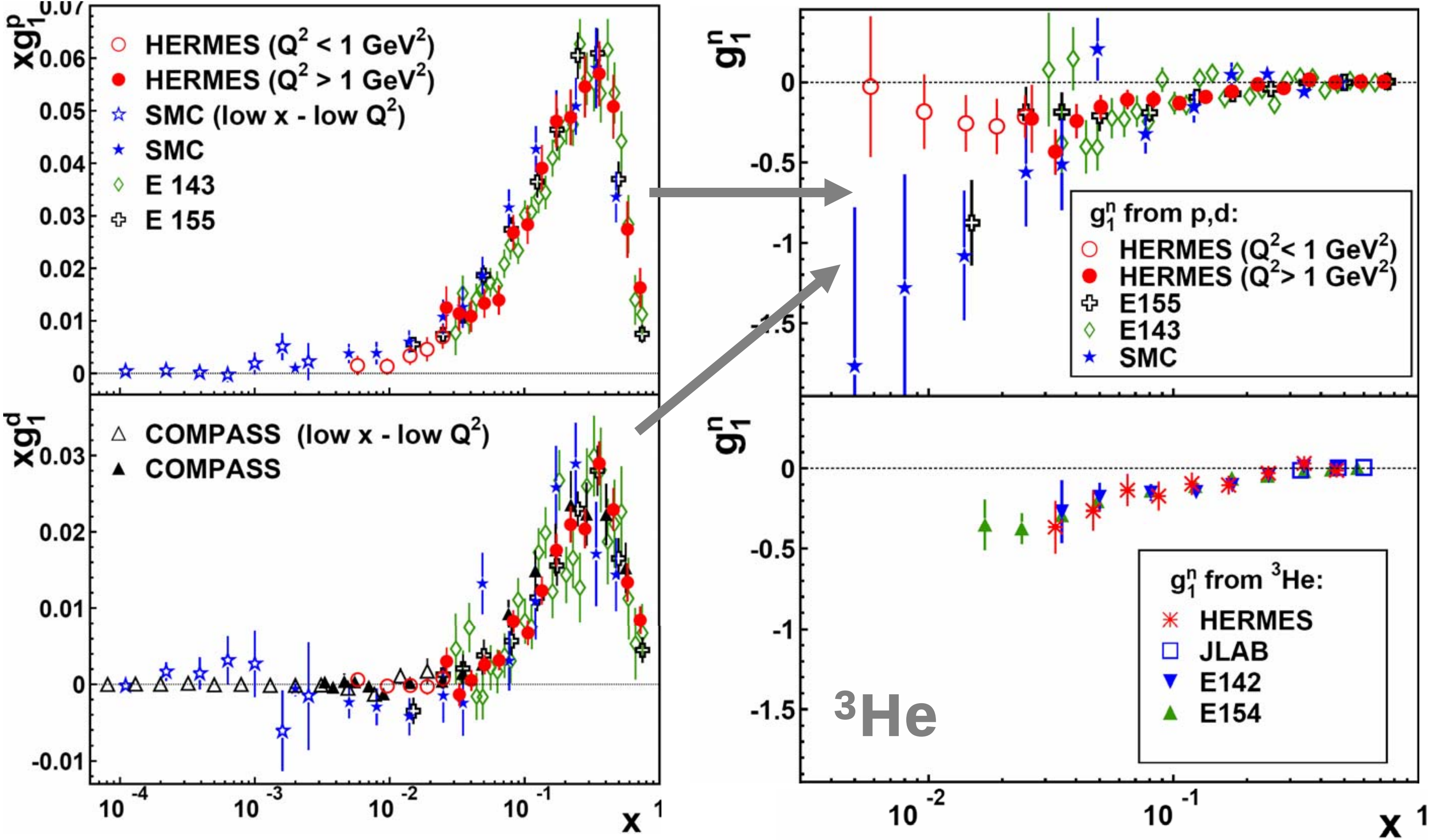
-the 2nd generation-




DIS

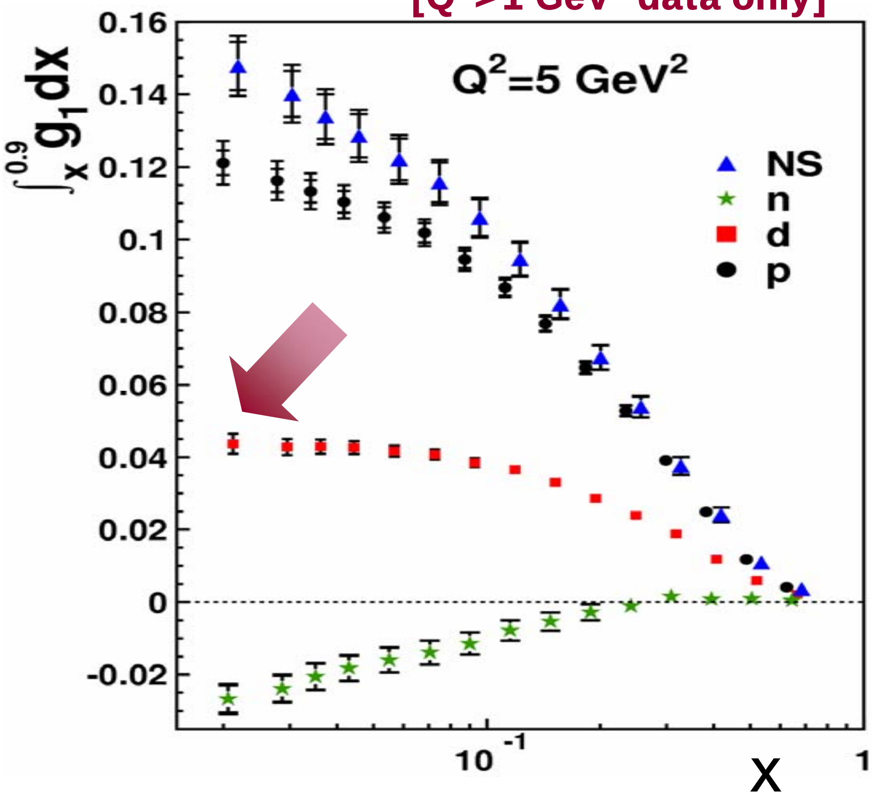
polarised structure function g_1

$$g_1(x) = \frac{1}{2} \sum_q e_q^2 \, (\Delta q + \Delta \bar{q})$$



first moment Γ_1^d and $\Delta\Sigma$

[Q² > 1 GeV² data only]



→assume *saturation* of Γ_1^d :

$$a_0^{\overline{MS}} = \Delta\Sigma \propto \frac{1}{\Delta C_s}\left[9\,\Gamma_1^d - \frac{1}{4} a_8 \Delta C_{NS}\right]$$

from theory

from hyperon beta decay

$a_0^{\overline{MS}} = \Delta\Sigma$ (exp) (theory) (evol)

$= 0.330 \pm 0.025 \pm 0.011 \pm 0.028$

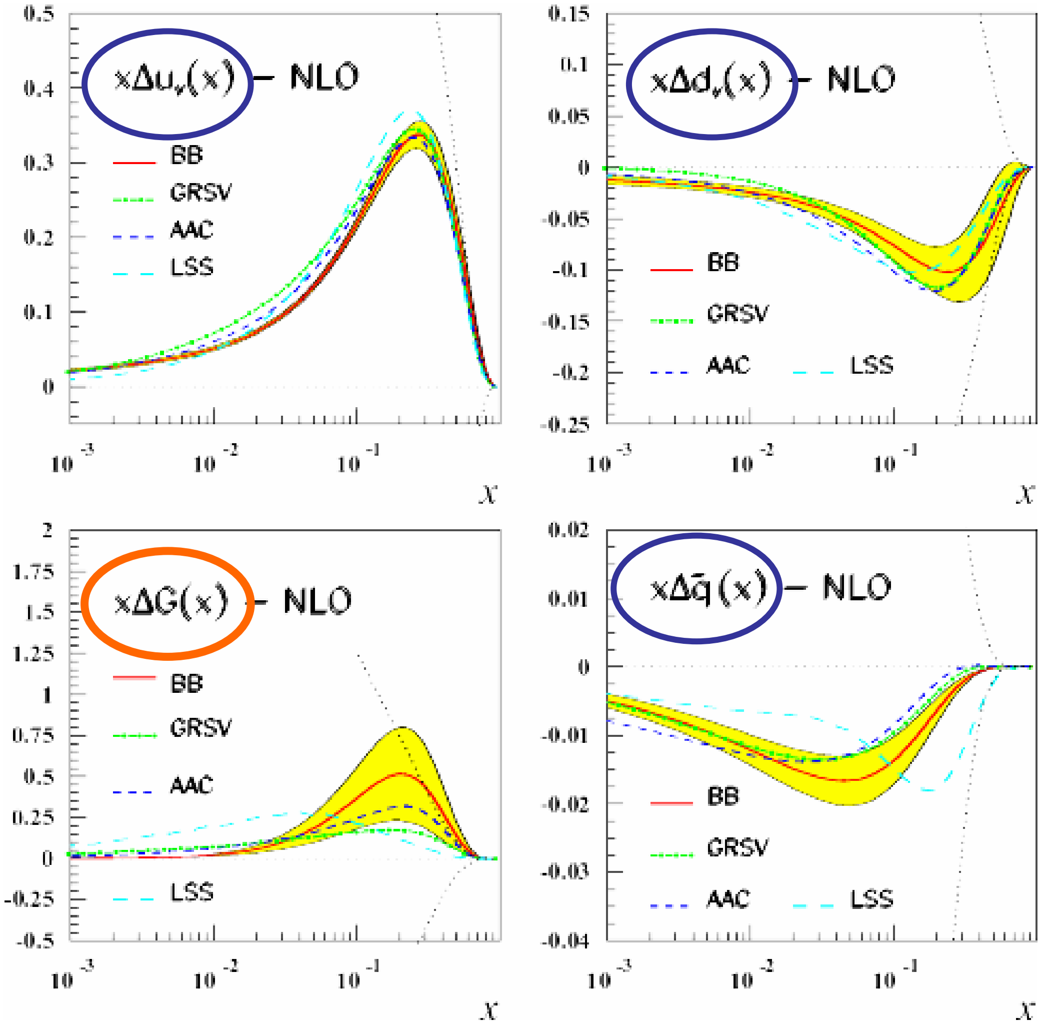
QCD-fit:

$a_0^{\overline{MS}} = \Delta\Sigma$

$= 0.35 \pm 0.03^{(stat)} \pm 0.05^{(sys+evol)}$

Δq and ΔG from inclusive data

$$g_1^{\mathrm{NLO}}(\mathrm{x},\mathrm{Q}^2) = g_1^{\mathrm{LO}} + \frac{1}{2}\left\langle e^2\right\rangle \sum_{\mathrm{q}} \mathrm{e}_{\mathrm{q}}^2\,[\Delta\mathrm{q}(\mathrm{x},\mathrm{Q}^2)\otimes C_{\mathrm{q}} + \Delta\mathrm{g}(x,\mathrm{Q}^2)\otimes C_{\mathrm{g}}]$$



- valence quarks are well determined:

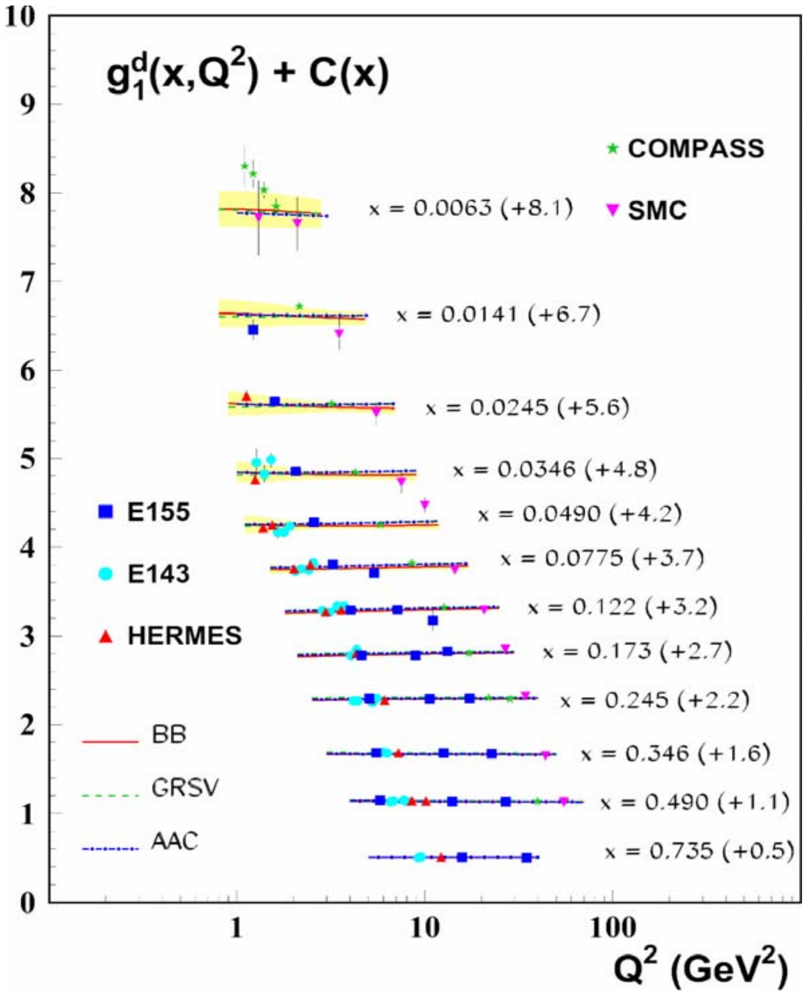
  $\Delta u_v > 0, \;\; \Delta d_v < 0$

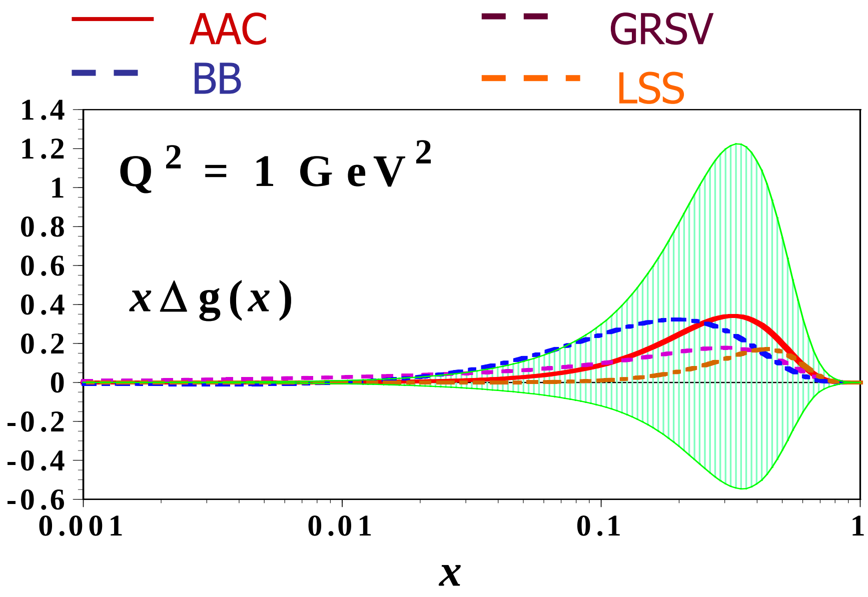
- gluons and sea quarks are poorly constraint by data

$SU(3)_f$ symmetry implicitly assumed

call for more direct probes…

kinematic range of polarised DIS exp:

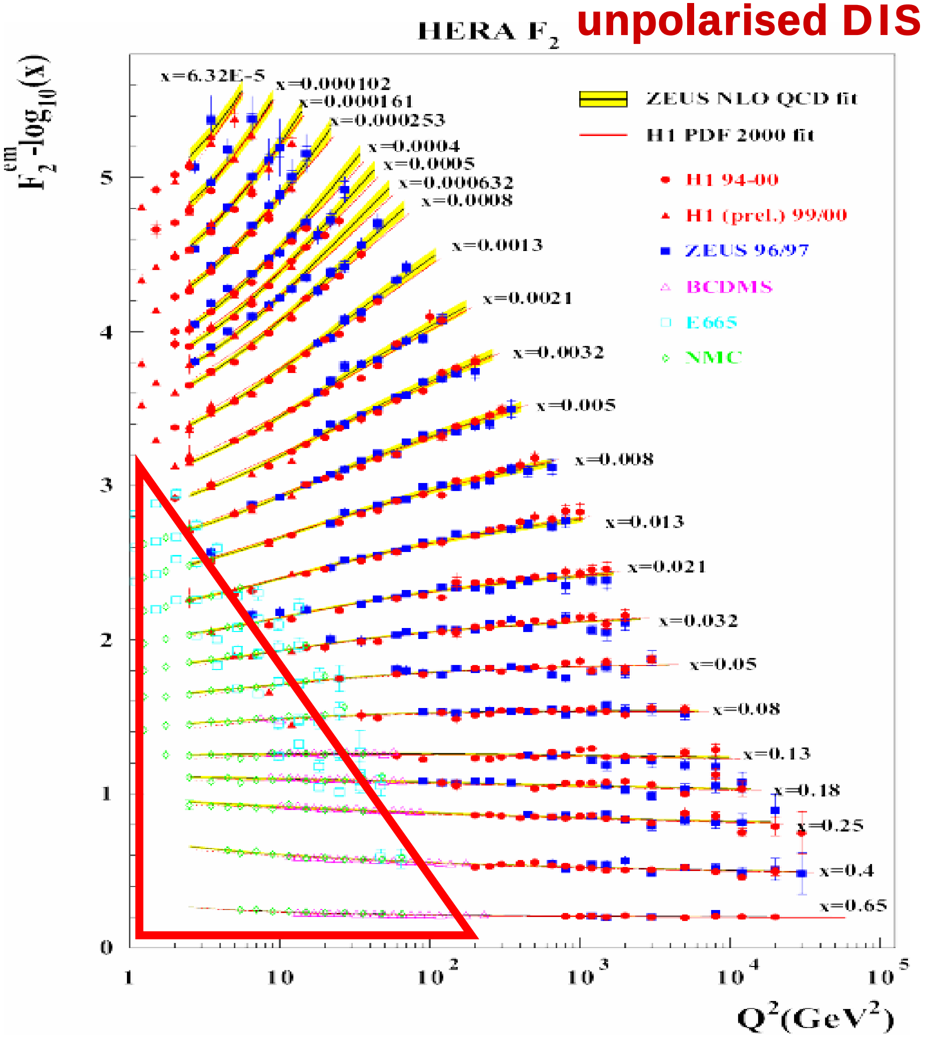


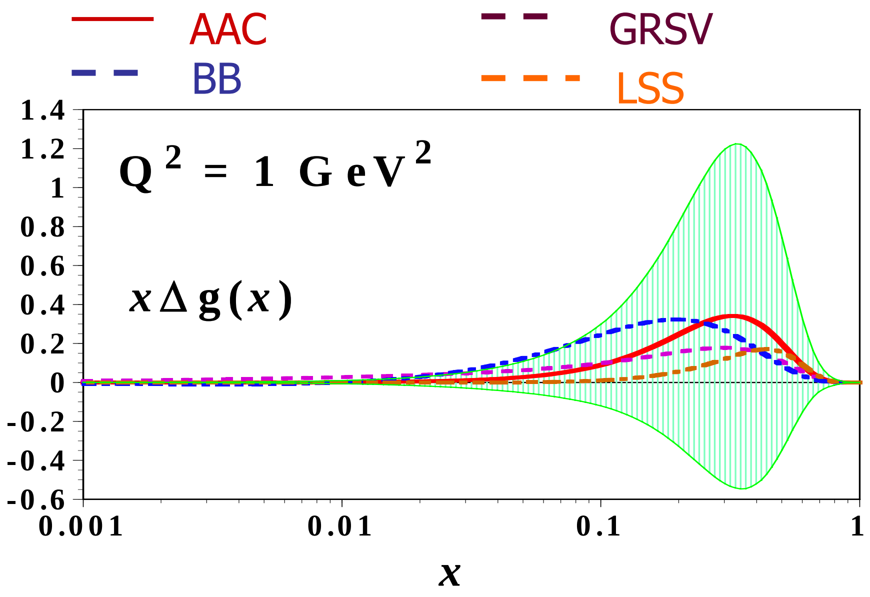


call for more direct probes…

kinematic range of polarised DIS exp:

unpolarised DIS



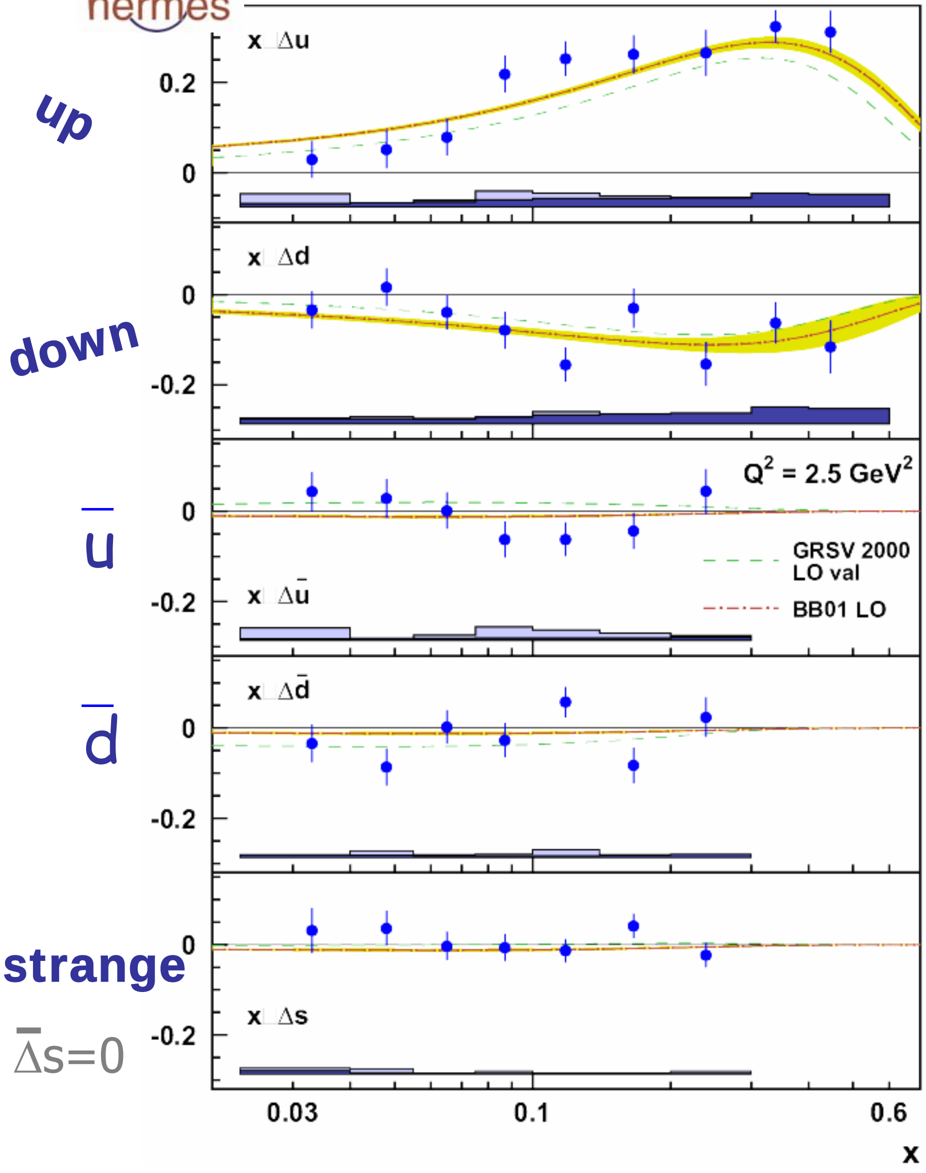


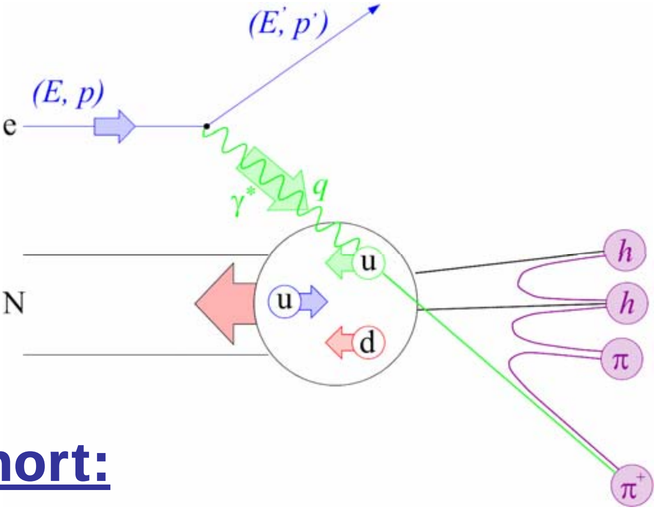
need *polarised collider* to extend kinematic coverage

→need *more direct* probes

flavour tagging: *semi-inclusive* DIS

[PRL92(2004), PRD71(2005)]





<u>in short:</u>

$\Delta u(x) > 0$ and large

$\Delta d(x) < 0$ and smaller

$\Delta s(x) \approx 0$

HERMES: only direct 5-flavour separation of polarised pdfs

more about *strange* quarks

- strange quarks carry no isospin, thus the same in proton and neutron
- → use isoscalar probe and target to extract *strange-quark* distributions

more about *strange* quarks

- strange quarks carry no isospin, thus the same in proton and neutron
- → use isoscalar probe and target to extract *strange-quark* distributions
- needed ingredients: $A_{1,d}(x,Q^2)$, $A_{1,d}^{K^+ + K^-}(x,z,Q^2)$ and $K^+ + K^-$ multiplicities
- *strange-quark* fragmentation function either directly from data or from parametrisations

→ **only assumptions:**

- isospin symmetry between proton and neutron
- charge conjugation invariance in fragmentation

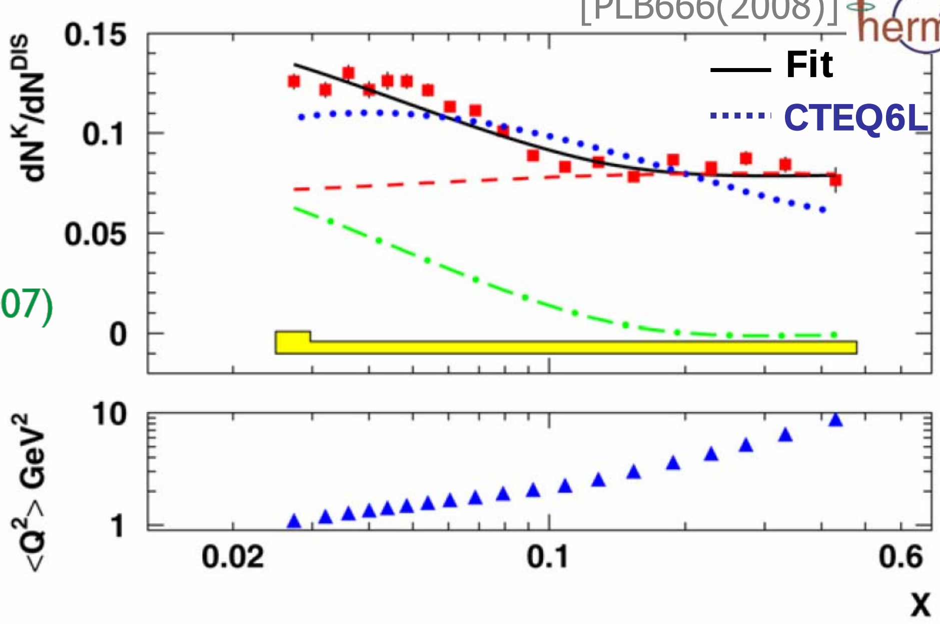
unpolarised *strange* quarks

$\mathrm{K}^{+} + \mathrm{K}^{-}$ multiplicities:

$$\int_{0.2}^{0.8} D_S^{\mathrm{K}}(z)dz = 1.27 \pm 0.13$$

de Florian et al., PRD75 (2007)

[PLB666(2008)]



unpolarised *strange* quarks

[PLB666(2008)]

$\mathrm{K}^+ + \mathrm{K}^-$ **multiplicities:**

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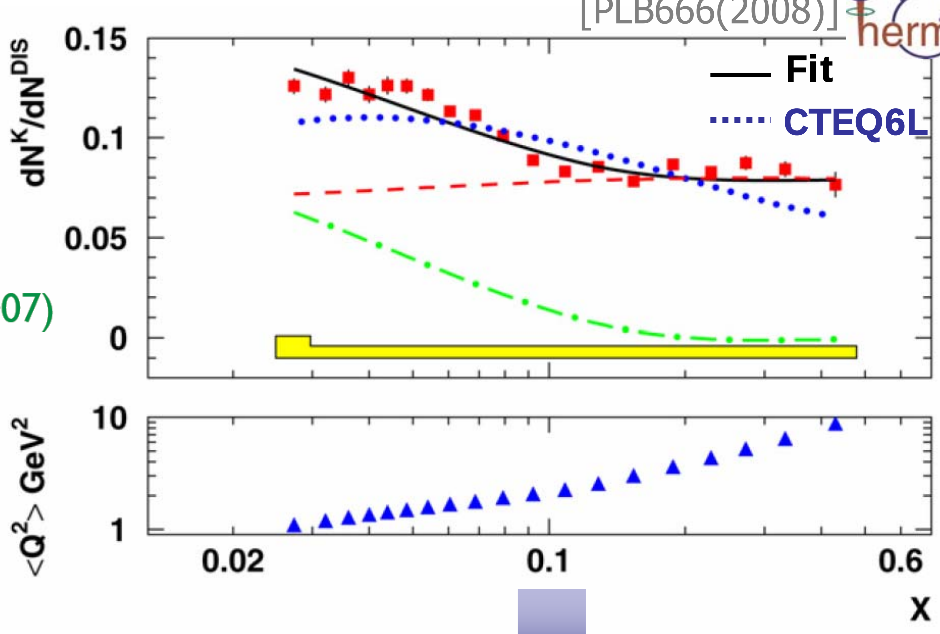
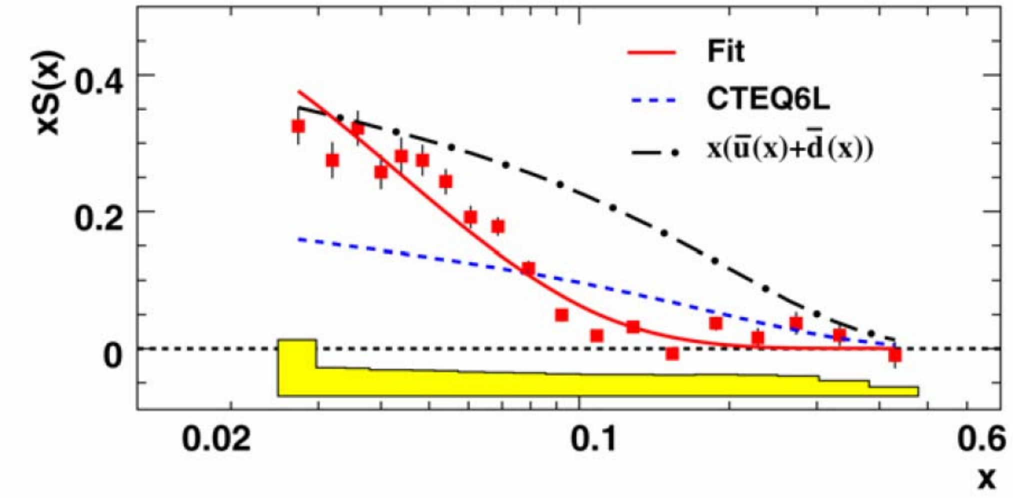


- S(x) non-zero for x<0.1 vanishes for x>0.1

- apparent discrepancy with CTEQ6L

- S(x) NOT an average of an isoscalar non-strange see



polarised *strange* quarks

- results consistent with previous flavour decomposition
- no sizeable negatively polarised strange sea as expected from inclusive DIS results
- sign of violation of $SU(3)_f$ symmetry or of substantial contribution from low-x region

axial charge: $a_8 = \Delta q_8 = \Delta Q - 2\Delta S$

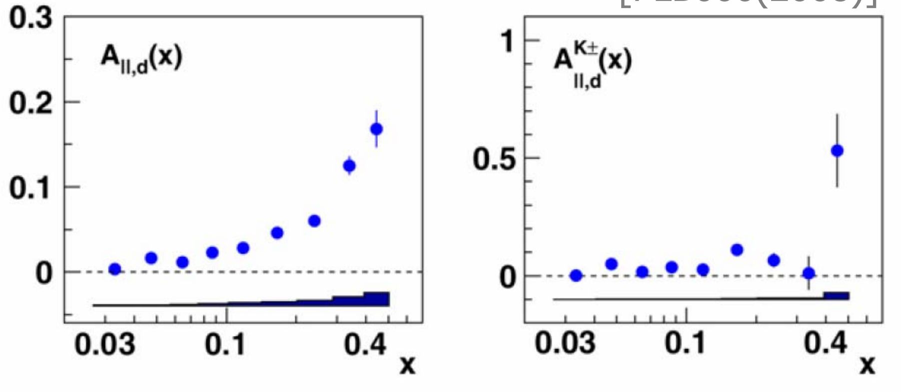
→ HERMES: $(0.02 < x < 0.6)$

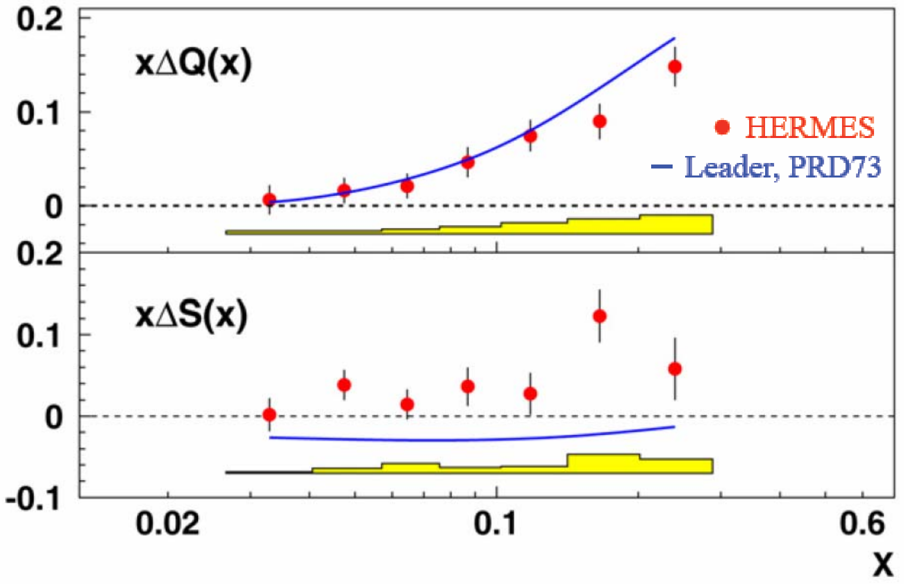
$\Delta q_8 = 0.285 \pm 0.073$

→ hyperon decay constants (SU(3) symm)

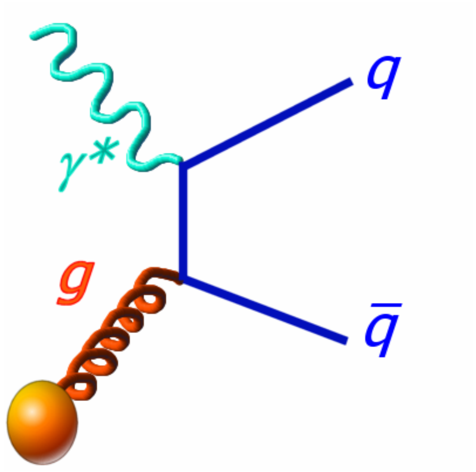
$\Delta q_8 = 0.586 \pm 0.031$

[PLB666(2008)]





‘direct’ measurement of ΔG

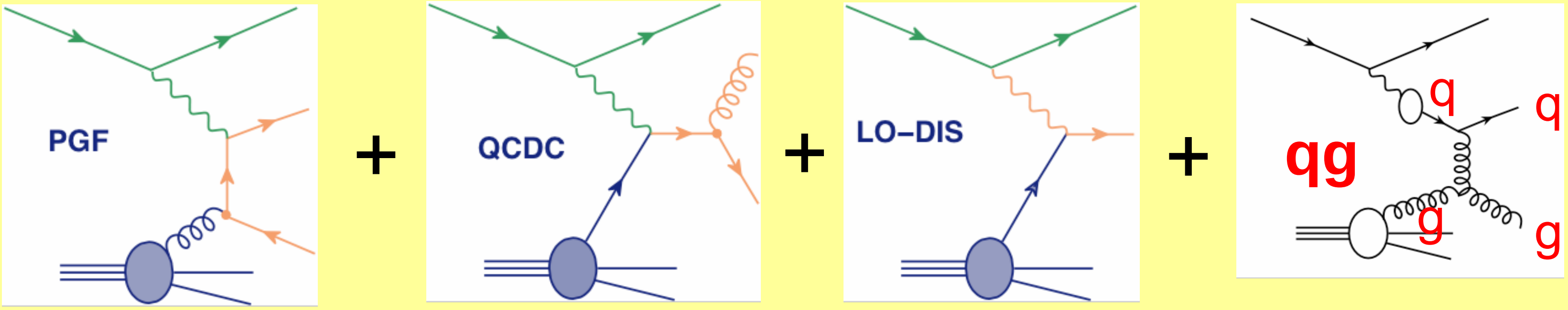


Photon-Gluon Fusion (PGF)

- golden channel: charm production
  → theoretically very clean
  → experimentally very challenging

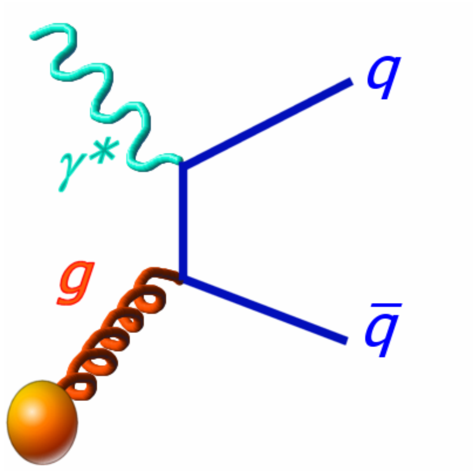
- @HERMES ($\sqrt{s}$=7 GeV):
  hadron production at high P_T
  → experimentally very clean
  → highly model dependent
  due to variety of background processes

other sub-processes make life hard:



extraction relies on Monte Carlo description of subprocesses (pythia)

direct measurement of ΔG



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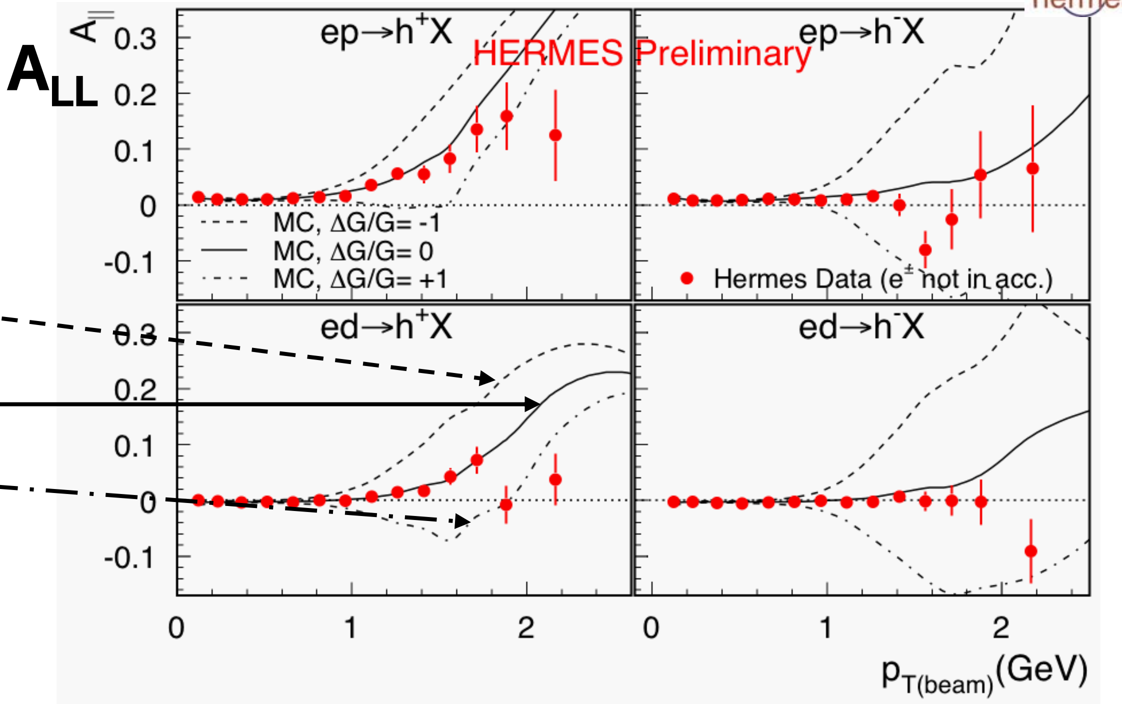


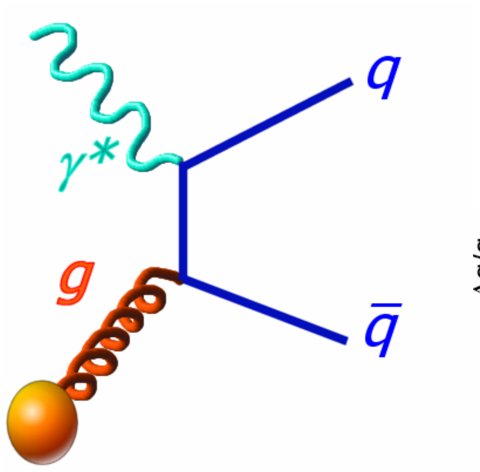
^{Pythia}MC:

$\Delta g/g = -1$

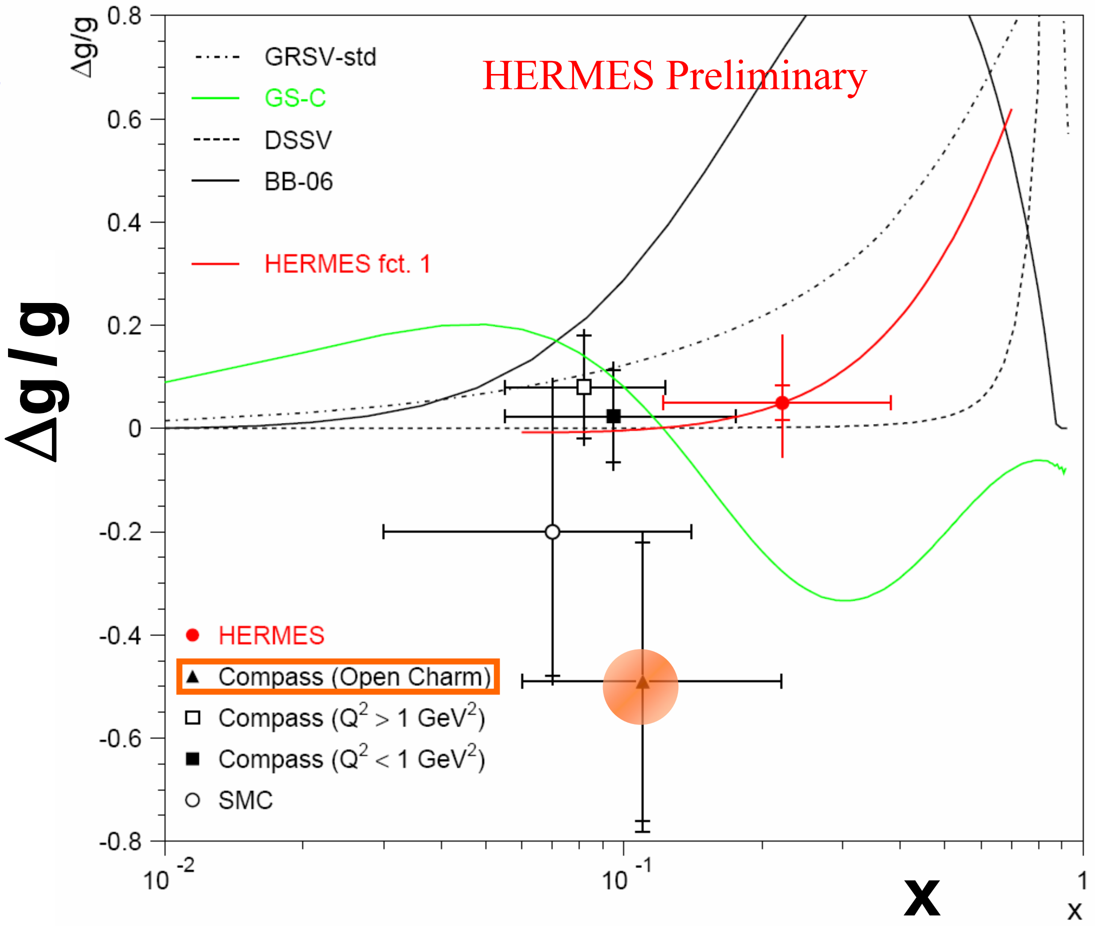
$\Delta g/g = 0$

$\Delta g/g = +1$

direct measurement of ΔG



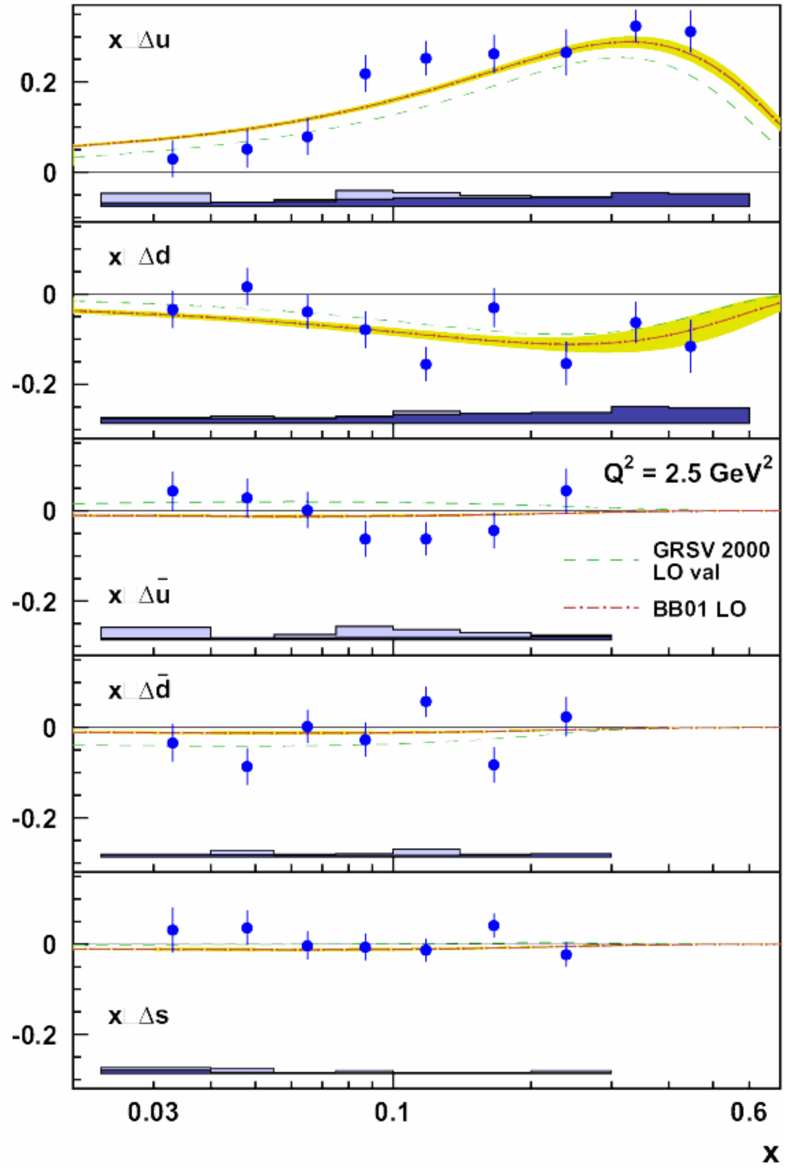
- **golden channel: charm production**
- **hadron production at high P_T**



@**x**[0.06,0.3]

Δg/g ~ zero!

quark and gluon polarisations

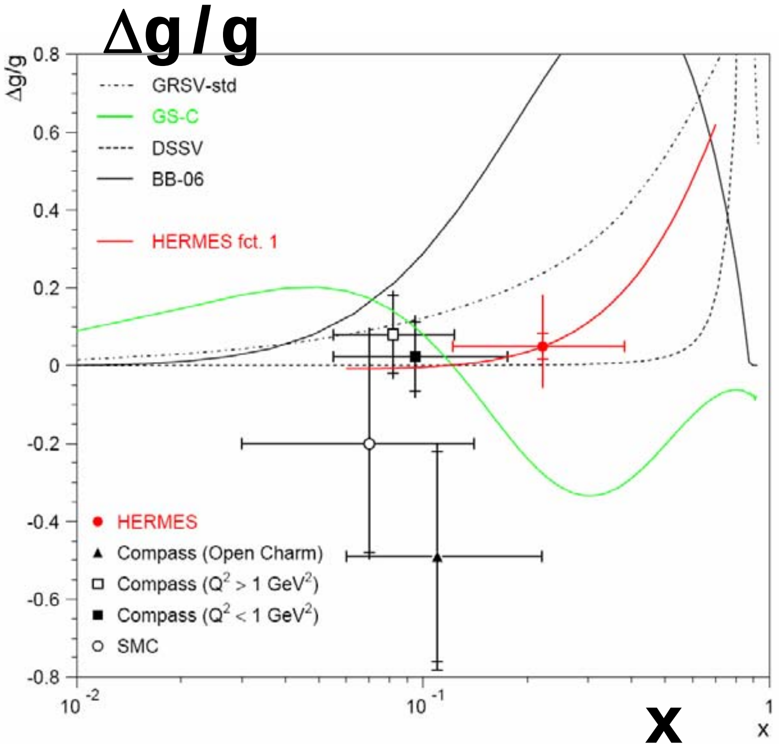


ΔΣ ~ 0.3

ΔG ~ 0

→ orbital angular momentum

→ next talk



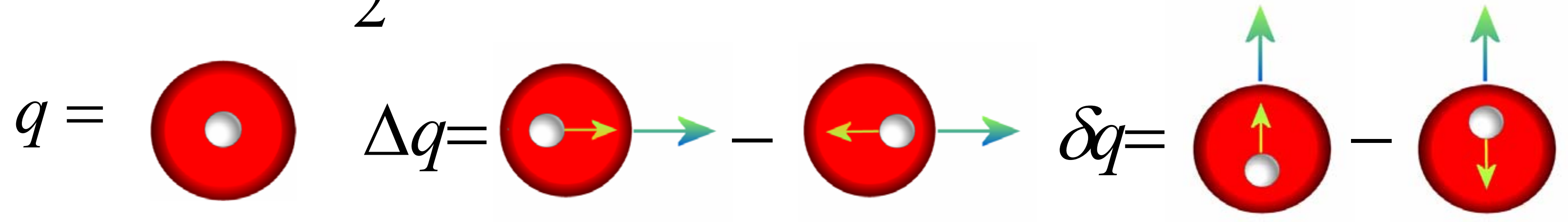
transverse spin phenomena

[courtesy of A. Bacchetta]

beyond collinear approximation

quark structure of the nucleon

$$\Phi^{\mathrm{Tw2}}_{\mathrm{Corr}}(x) = \frac{1}{2}\left\{ q(x) + \mathrm{S}_{\mathrm{L}}\Delta q(x)\gamma_5 + \delta q(x)\gamma_5\gamma^1\mathrm{S}_{\mathrm{T}} \right\} n^+$$



unpolarised quarks and nucleons

longitudinally polarised quarks and nucleons

transversely polarised quarks and nucleons

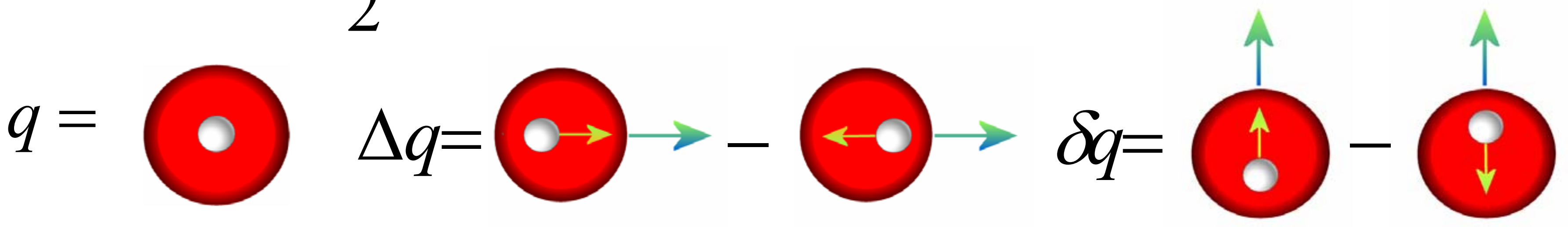
[also: h_1^q, $\Delta_T q$]

Peculiarities of δq

- probes relativistic nature of quarks
  →otherwise $\delta q = \Delta q$
- no gluon analog for spin-1/2 nucleon
  →different Q^2 evolution than Δq
- sensitive to *valence* quark polarisation
- only known way to obtain tensor charge

quark structure of the nucleon

$$\Phi^{\mathrm{Tw2}}_{\mathrm{Corr}}(x) = \frac{1}{2}\left\{ q(x) + \mathrm{S}_{\mathrm{L}}\Delta q(x)\gamma_5 + \delta q(x)\gamma_5\gamma^1\mathrm{S}_{\mathrm{T}} \right\} n^+$$



unpolarised quarks
and nucleons

longitudinally polarised
quarks and nucleons

transversely polarised
quarks and nucleons

[also: h_1^q, $\Delta_T q$]

δq: *helicity-flip of both nucleon and quark*

δq is *chiral-odd* → **needs a chiral odd partner:**

$$\text{SIDIS: } \sigma^{ep\to ehX} \propto \sum_q \sigma^{eq\to eq} \otimes \delta q(x) \otimes FF^{q\to h}(z)$$

chiral-odd
PDF

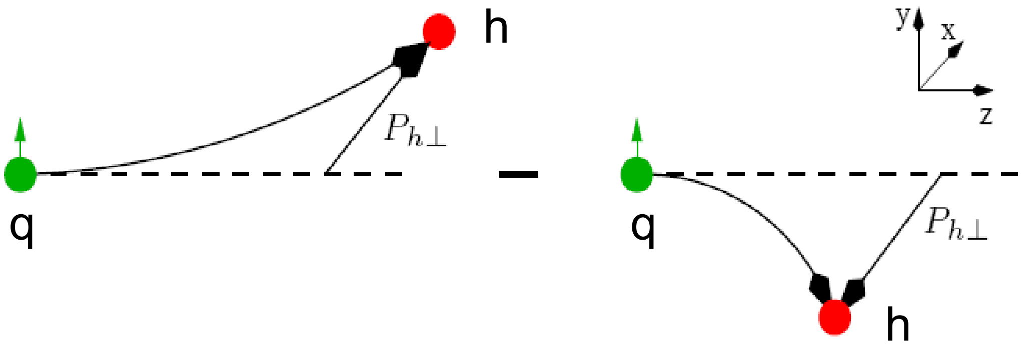
chiral-odd
FF

chiral-even

chiral-odd fragmentation function acts as polarimeter of transverse quark polarisation

"*Collins-effect*"

- ***Collins FF*** **$H_1^{\perp}(z,k_T^2)$** correlates *transverse spin* of fragmenting quark and *transverse momentum* $P_{h\perp}$ of produced hadron h



→ left-right (azimuthal) asymmetry in the direction of the outgoing hadron

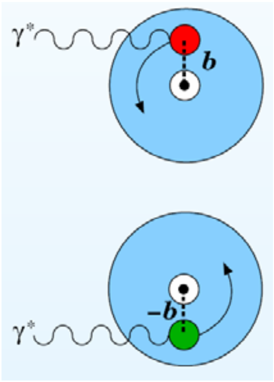
our observable: single-spin azimuthal asymmetry

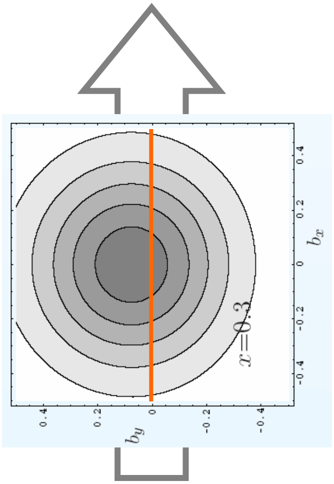
is this observable unique?

"Sivers-effect"

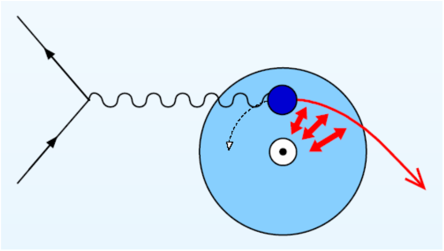
- another mechanism that produces single-spin azimuthal asymmetries:

Sivers distribution function : distribution of unpolarised quarks in a transversely polarised nucleon → describes *spin-orbit correlations*





$u_X\left(x,\boldsymbol{b}_\perp\right)$



[Matthias Burkardt: chromodynamic lensing]

a non-zero Sivers fct. requires non-zero orbital angular momentum !

Sivers fct. is (naively) time-reversal *odd* !

polarised DIS^h cross section

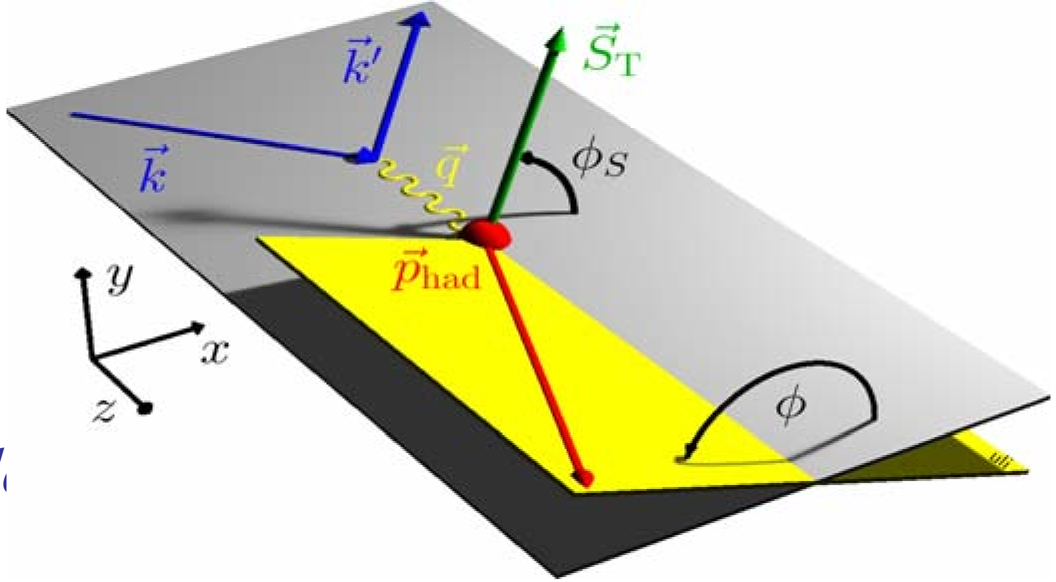
σ_{UU}

$$d\sigma^h(x,y,z,\boxed{P_{h\perp},\phi,\ldots}) =$$

$$\boxed{d\sigma_{UU}} + \cos 2\phi \, d\sigma_{UU} + \frac{1}{Q}$$

q(x)

$$+ S_L \Big[\sin 2\phi \, d\sigma_{UL} + \frac{1}{Q} \sin\phi \, d$$

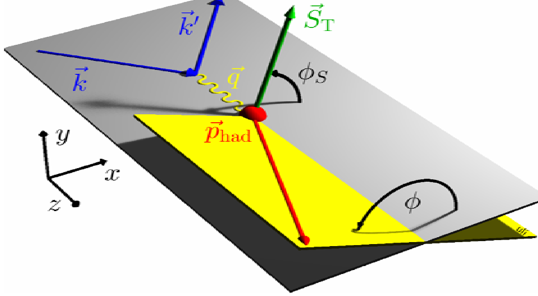


Δq(x)

$$+ S_T \Big[\sin(\phi+\phi_S) d\sigma_{UT} + \sin(\phi-\phi_S) d\sigma_{UT} + \sin(3\phi-\phi_S) d\sigma_{UT} + \frac{1}{Q} \ldots \Big]$$

$$+ \lambda S_T \Big[\cos(\phi-\phi_S) + \frac{1}{Q} \ldots \Big] + \ldots.$$

polarised DIS^h cross section



$$d\sigma^h(x,y,z,\boxed{P_{h\perp},\phi,\ldots}) =$$

$$d\sigma_{UU} + \cos 2\phi\, d\sigma_{UU} + \frac{1}{Q}\cos\phi\, d\sigma_{UU} + \lambda\frac{1}{Q}\sin\phi\, d\sigma_{LU}$$

q(x)

$$+ S_L\left[\sin 2\phi\, d\sigma_{UL} + \frac{1}{Q}\sin\phi\, d\sigma_{UL}\right] + \lambda S_L\left[d\sigma_{LL} + \frac{1}{Q}\cos\phi\, d\sigma_{LL}\right]$$

$\delta q \otimes H_1^\perp + f_{1T}^\perp \otimes D_1 + h_L \ldots$

Δq(x)

$$+ S_T\left[\sin(\phi+\phi_S)\,d\sigma_{UT} + \sin(\phi-\phi_S)\,d\sigma_{UT} + \sin(3\phi-\phi_S)\,d\sigma_{UT} + \frac{1}{Q}\ldots\right]$$

$\delta q \otimes H_1^\perp$

$f_{1T}^\perp \otimes D_1$

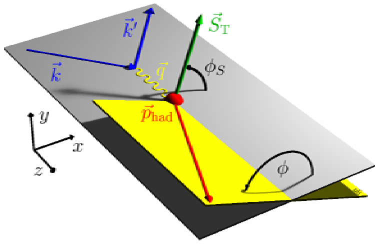
transversity

(Collins effect)

SIDIS with *transversely* polarised targets but not only…

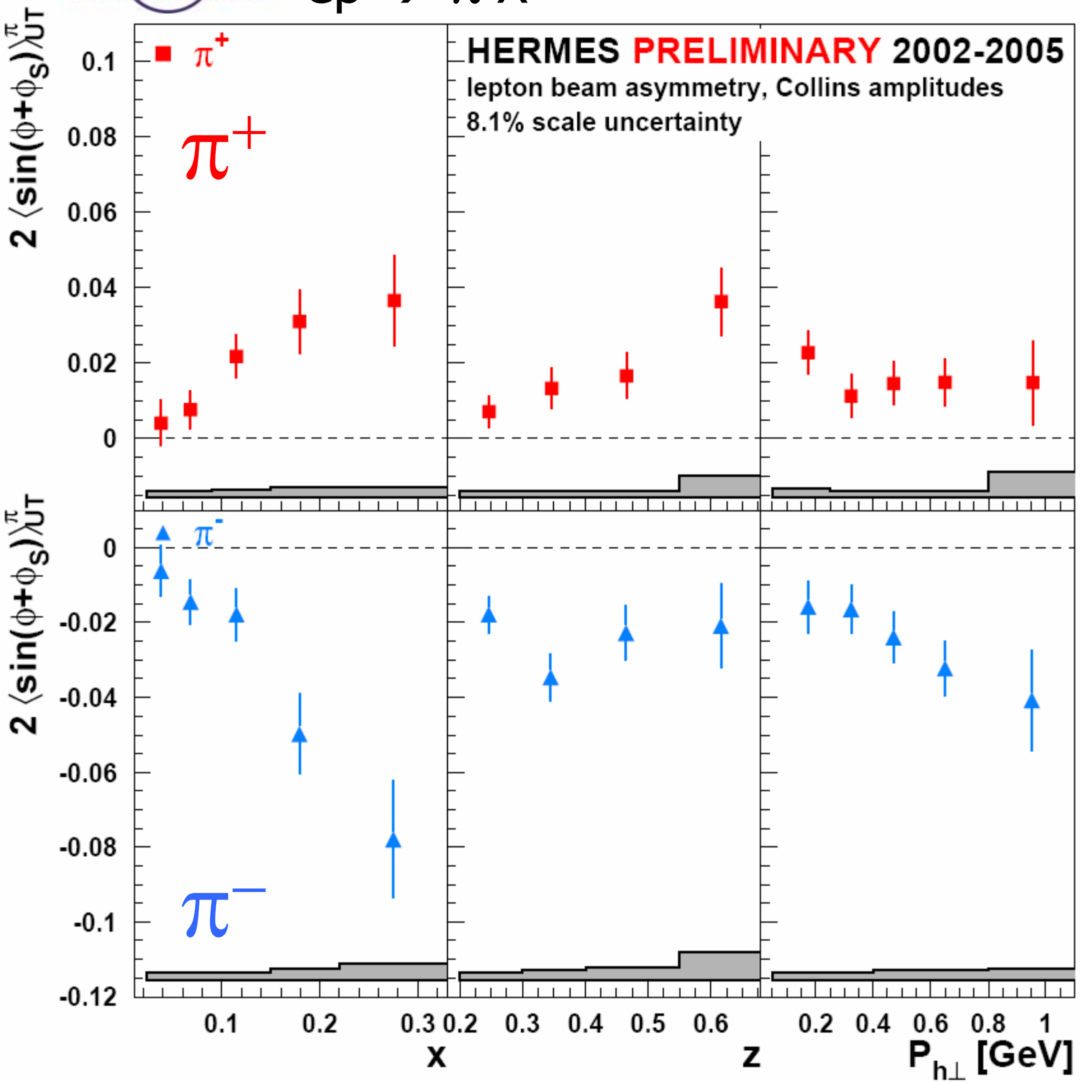
$$+\lambda S_T\left[\cos(\phi-\phi_S) + \frac{1}{Q}\ldots\right] + \ldots$$

Collins asymmetries



$$\delta q(x) \otimes H_1^{\perp q}(z)$$

ep↑→ π X



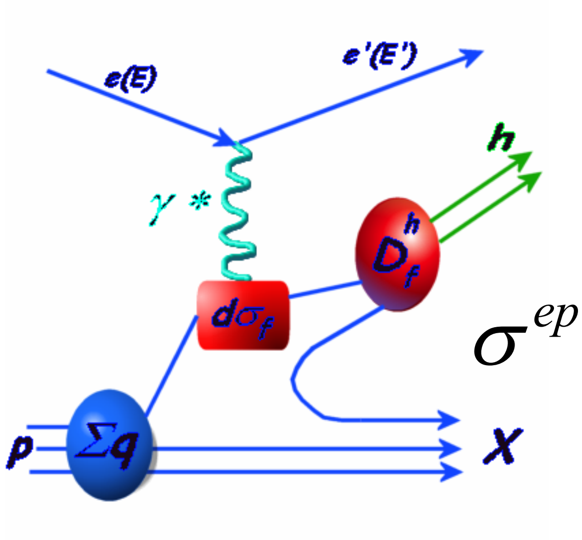
first time: *transversity* & *Collins FF* are **non-zero!**

- π^+ asymmetries positive – no surprise: u-quark dominance and expect $\delta q>0$ since $\Delta q>0$

- large negative π^- asymmetries – **ARE** a surprise: suggests the *disfavoured CollinsFF* being large and with oposite sign:

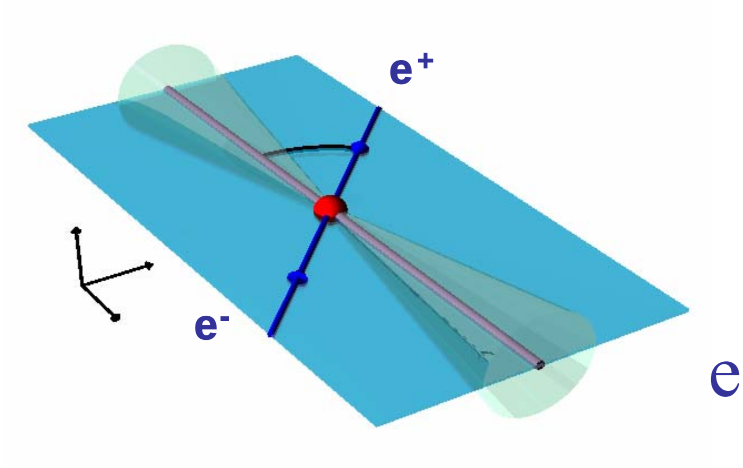
$$H_1^{\perp,\text{disfav}}(z) \boxed{\approx -} H_1^{\perp,\text{fav}}(z)$$

extracting *transversity*



$$\sigma^{ep\rightarrow ehX} \propto \sum_q \sigma^{eq\rightarrow eq} \otimes \delta q(x) \otimes FF^{q\rightarrow h}(z)$$

spin-dependent
fragmentation
function
→
e^+e^-

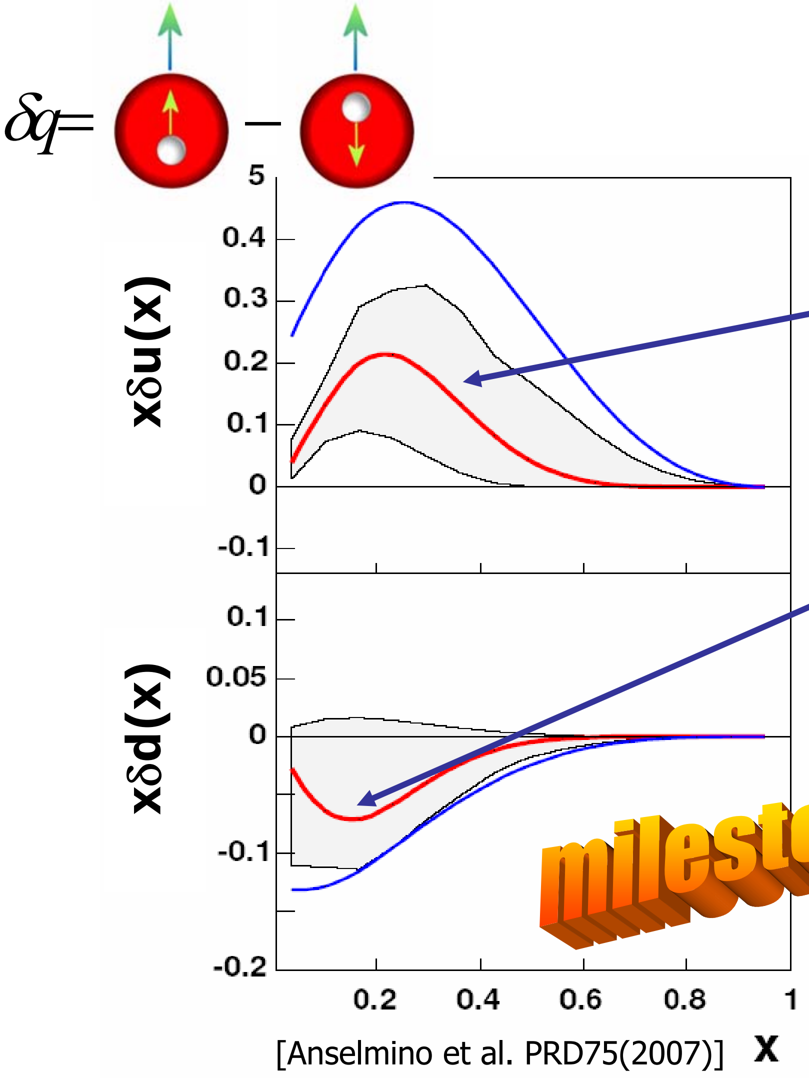


BELLE

$$e^+e^- \rightarrow \pi^+_{\text{jet1}}\ \pi^-_{\text{jet2}}\ X$$

first glimpse of transversity

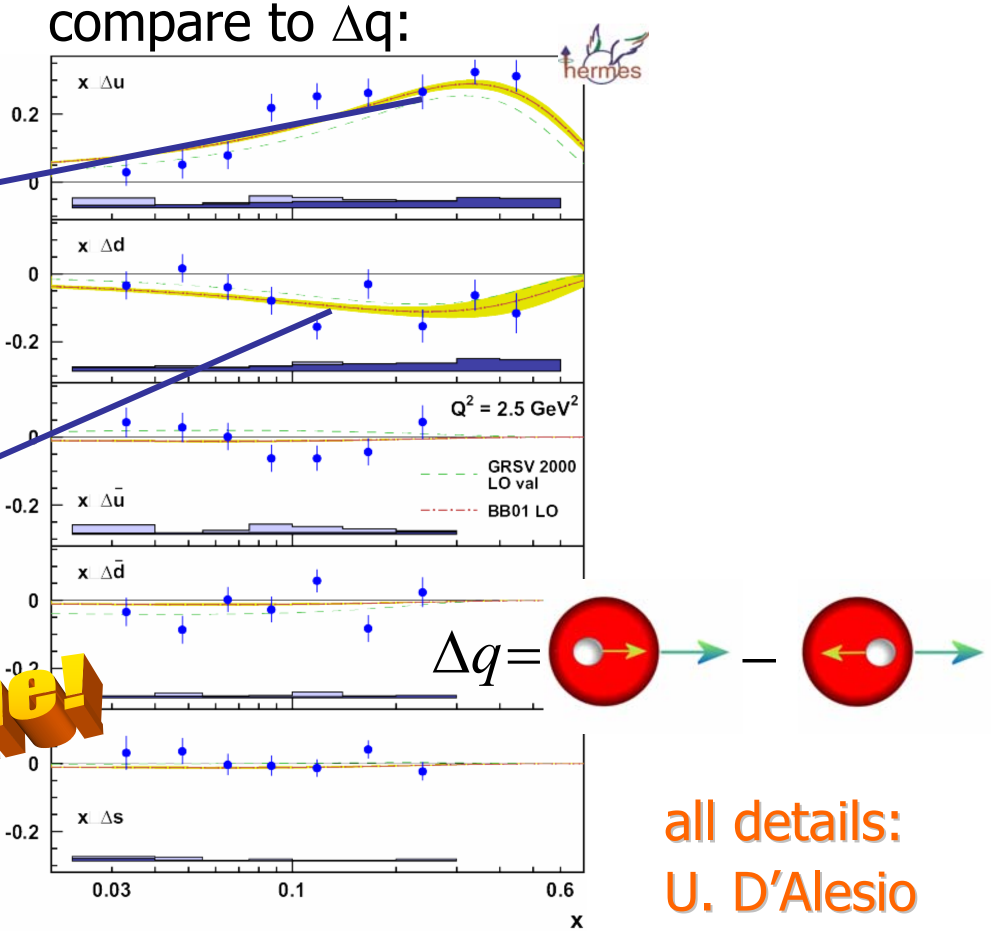
global, simultaneous fit:



[Anselmino et al. PRD75(2007)]

milestone!

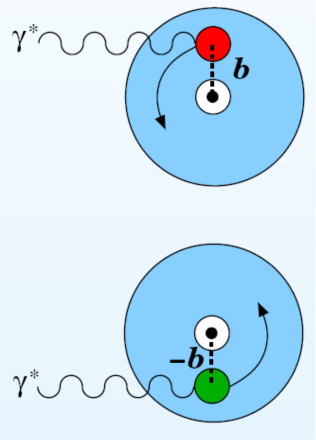
compare to Δq:

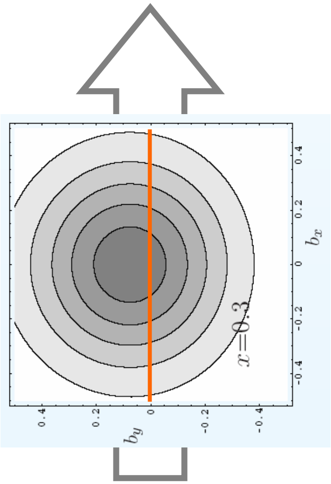


all details:
U. D'Alesio

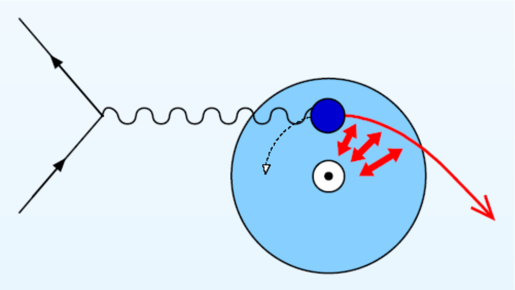
spin-orbit structure

Sivers function:





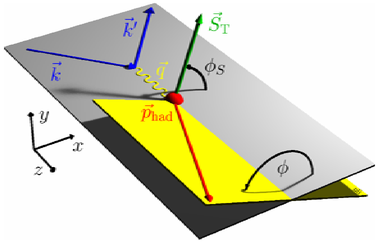
$u_X\ (x, \boldsymbol{b}_\perp)$

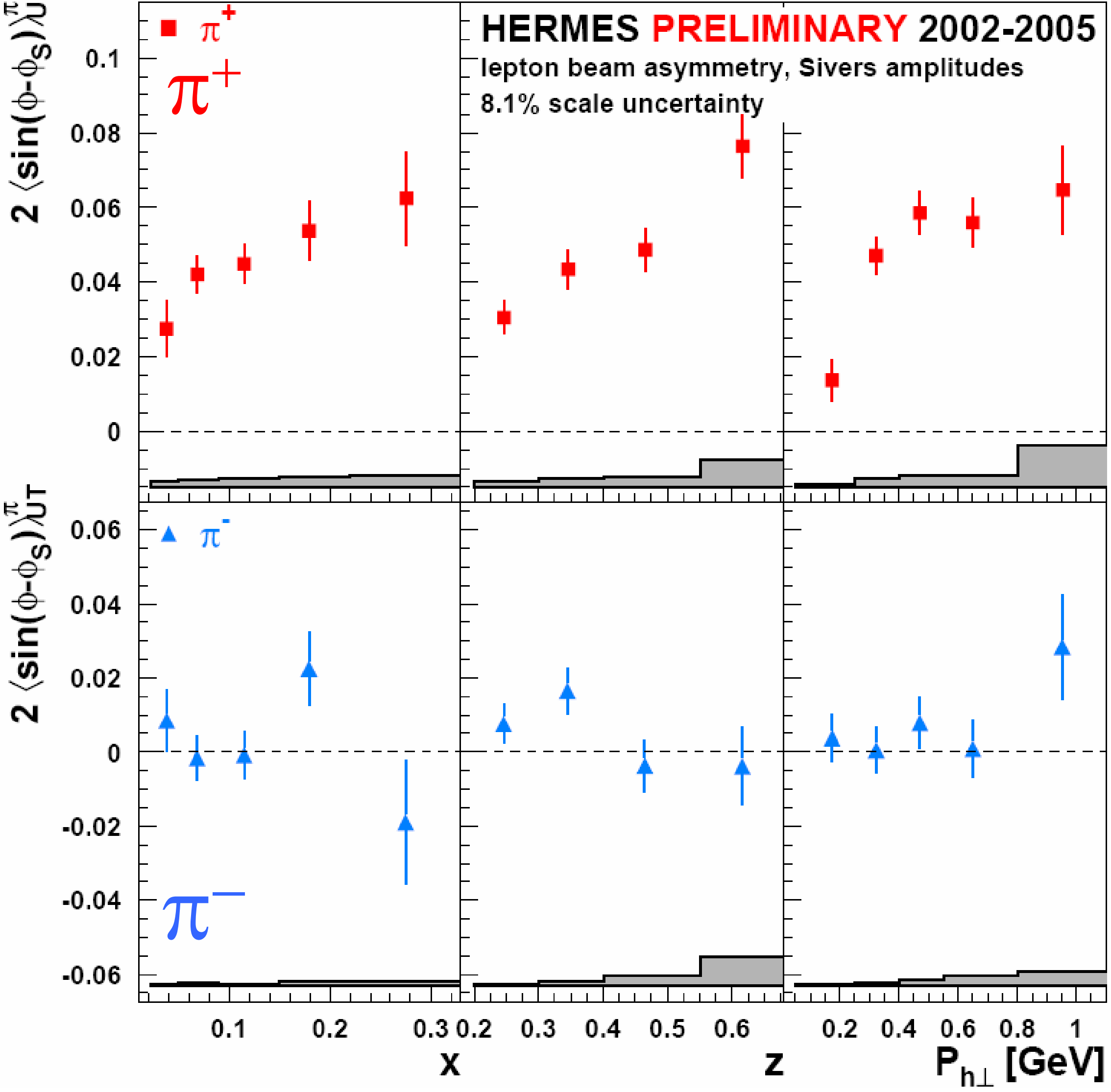


[Matthias Burkardt]

a non-zero Sivers fct. requires non-zero orbital angular momentum !

Sivers asymmetries



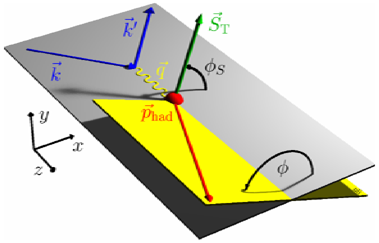


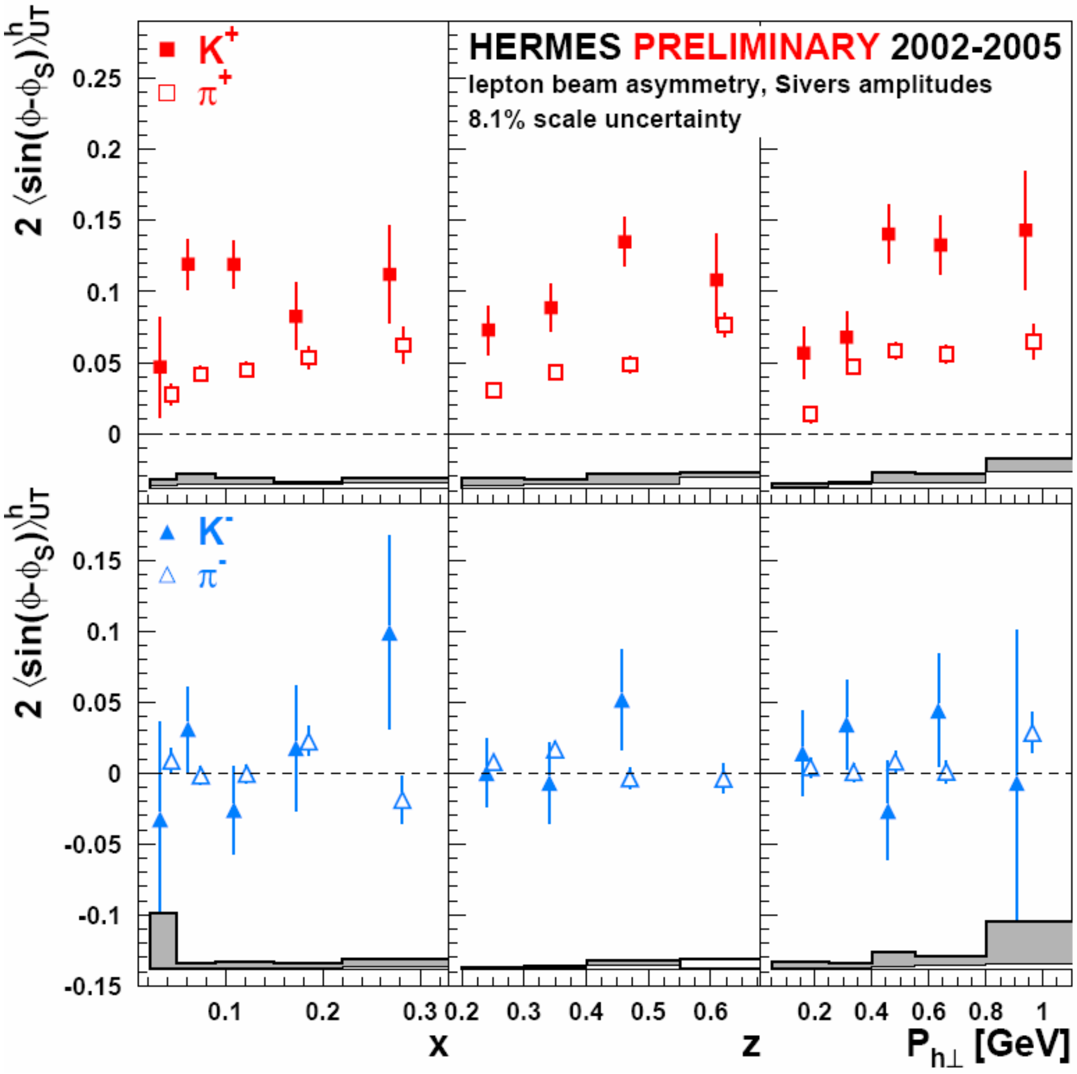
$$f_{1T}^{\perp q}(x) \otimes D_1^q(z)$$

π^+ are subtantial and positive:

- first unambiguous evidence for a **non-zero T-odd** distribution function in DIS
- a signature for quark orbital angular momentum !

Sivers asymmetries





$$f_{1T}^{\perp q}(x) \otimes D_1^q(z)$$

- SURPRISE:

K$^+$ amplitude 2.3±0.3 times larger than for π^+

→ conflicts with usual expectations based on u-quark dominance

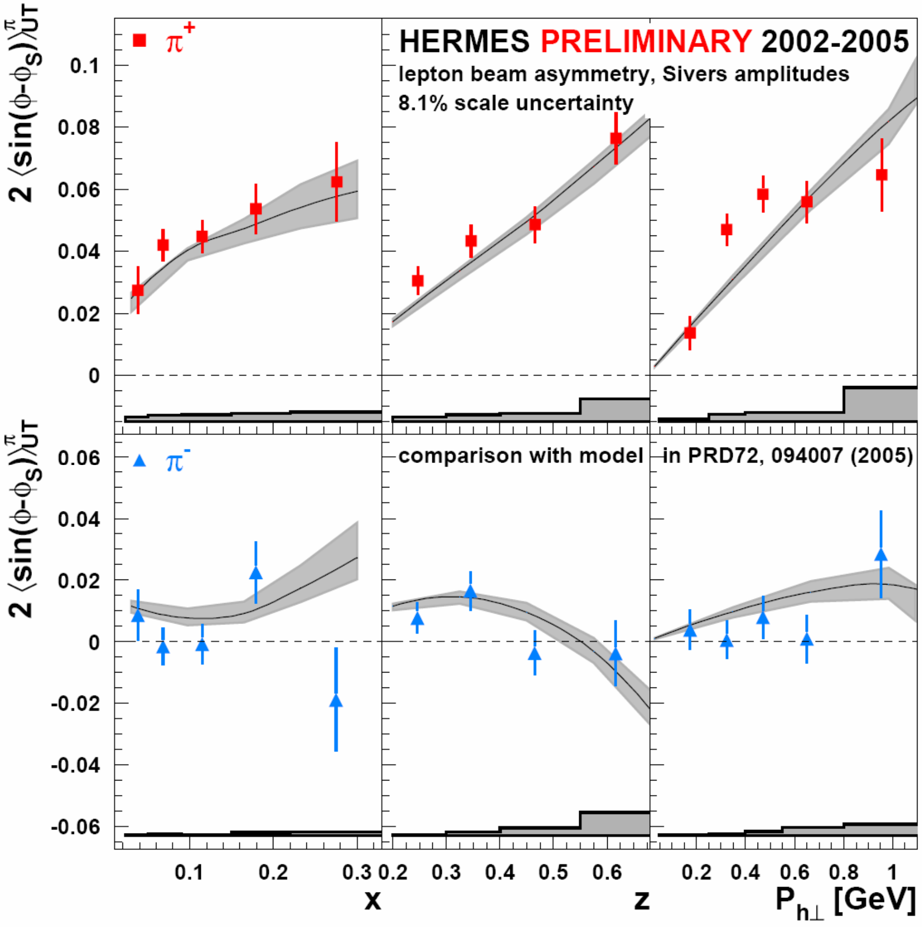
→ suggests substantial magnitude of the Sivers fct. for sea quarks

$$K^+ = |u\bar{s}\rangle \quad \pi^+ = |u\bar{d}\rangle$$

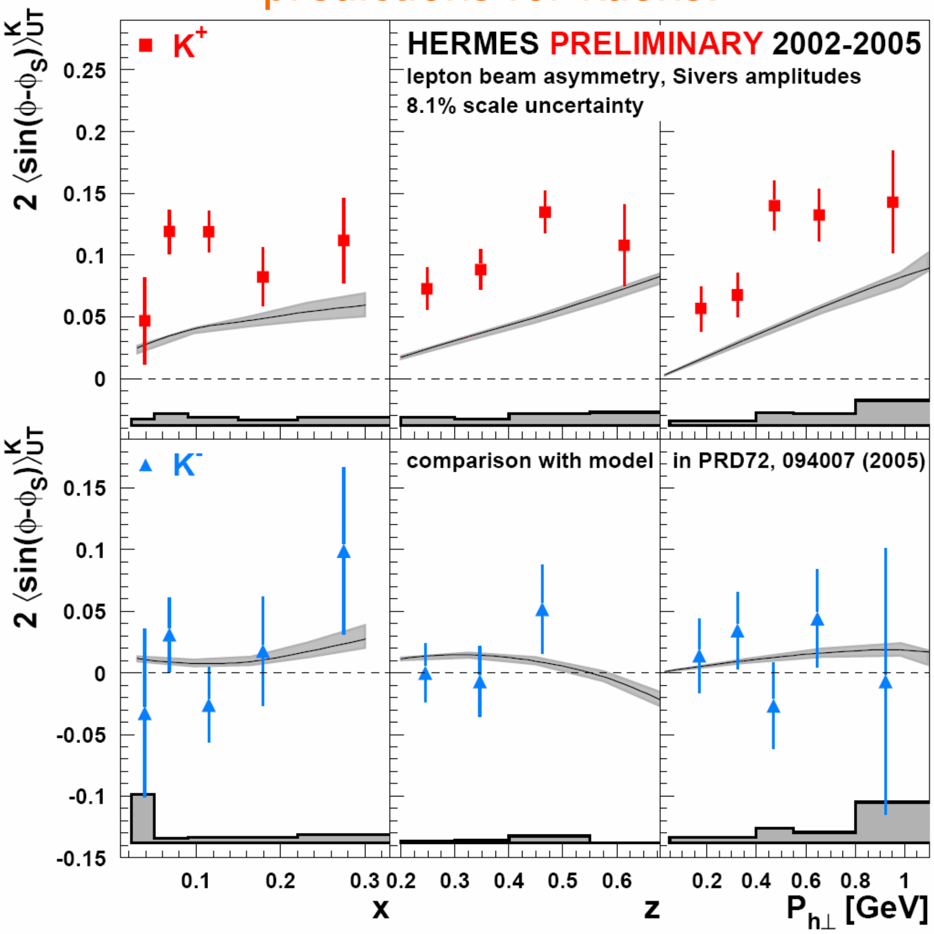
comparison to models

[Anselmino et al. PRD72(2005)]

excellent description of pion data
but: cannot constrain sea



predictions for kaons:



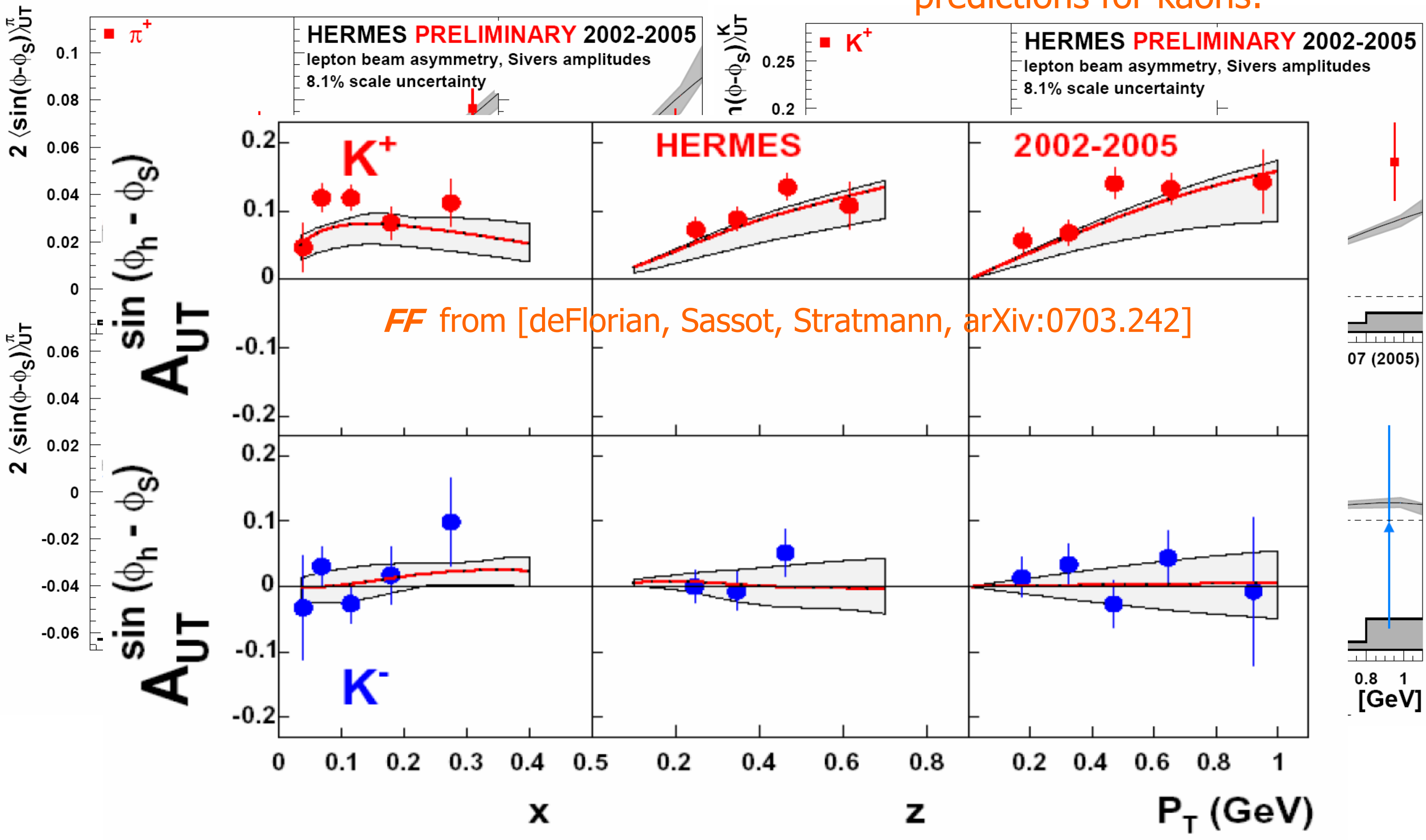
kaon data suggest that sea quark contribution may be significant

comparison to models

[Anselmino et al. PRD72(2005)]

excellent description of pion data
but: cannot constrain sea

predictions for kaons:

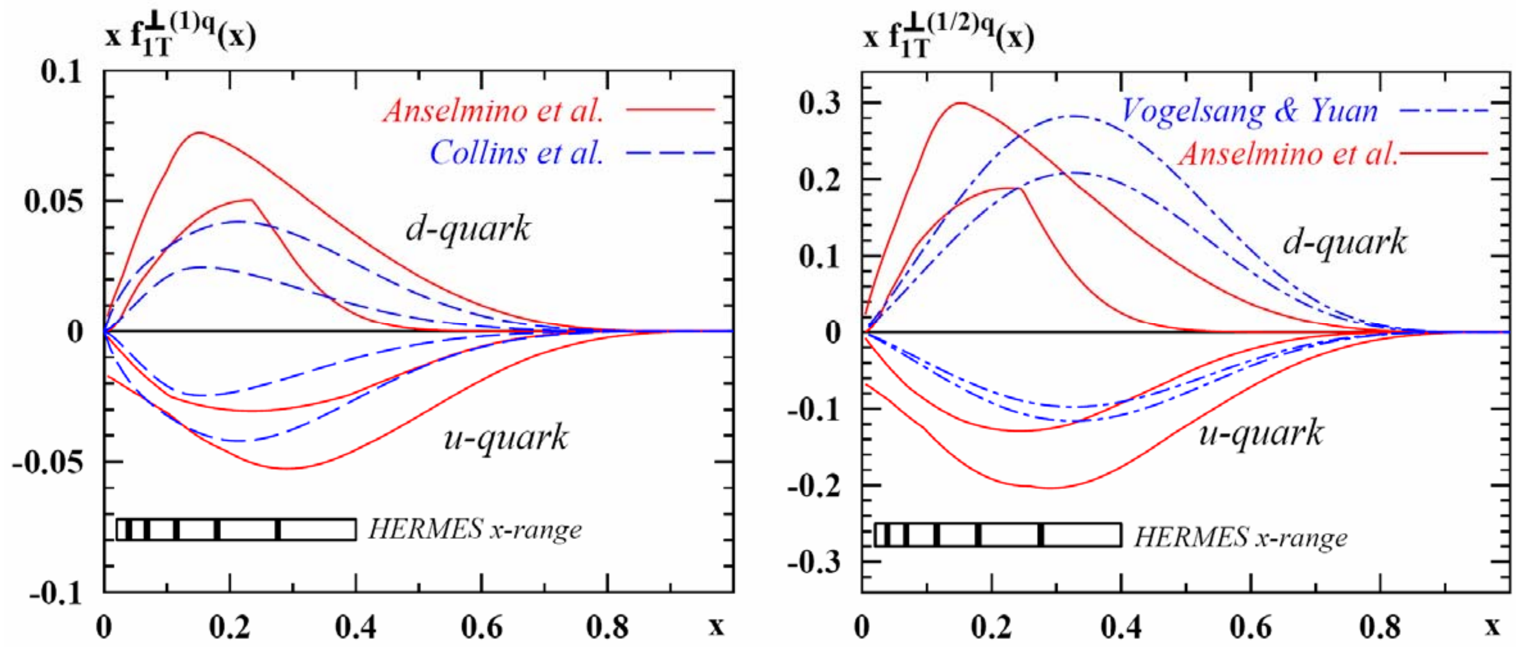


FF from [deFlorian, Sassot, Stratmann, arXiv:0703.242]

extracting the *Sivers* function

$$A_{\mathrm{UT}}^{\sin(\phi-\phi_S)} \propto f_{1\mathrm{T}}^{\perp q}(x) \otimes D_1^q(z)$$

usual unpolarised fragmentation function



ToDo:

crucial test of pQCD:

$$(f_{1\mathrm{T}}^{\perp q})_{\mathrm{DIS}} \approx \enclose{circle}{-}(f_{1\mathrm{T}}^{\perp q})_{\mathrm{DY}}$$

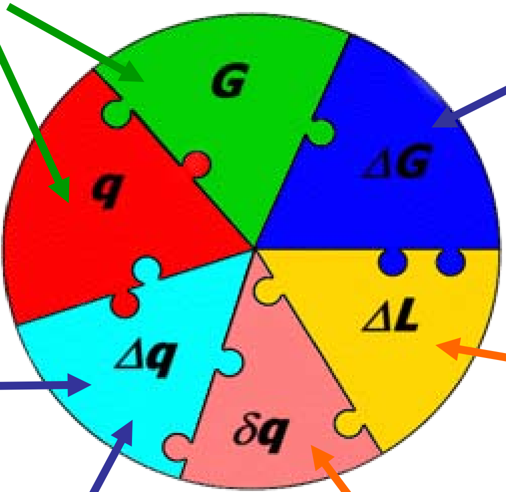
Polarized Antiproton EXperiments

@FAIR (GSI)

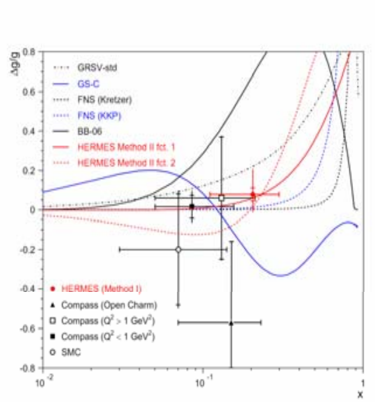
structure of the nucleon

from unpolarised DIS

from polarised DIS :

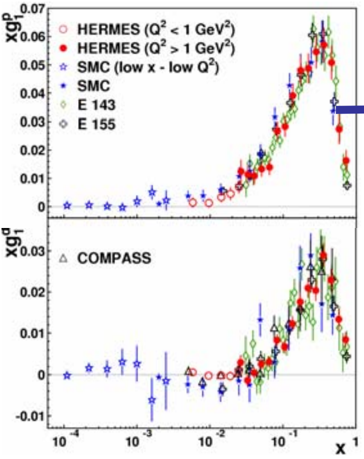


first glimpse

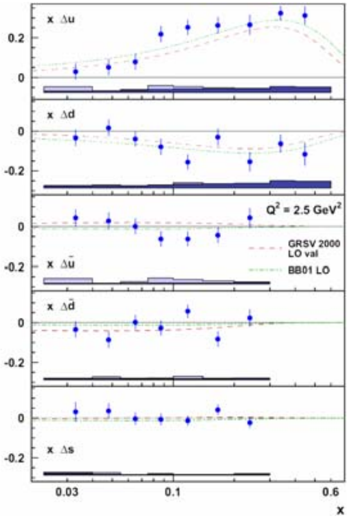


→$a_0 = \Delta\Sigma$

$= 0.330 \pm 0.025^{(exp)}$



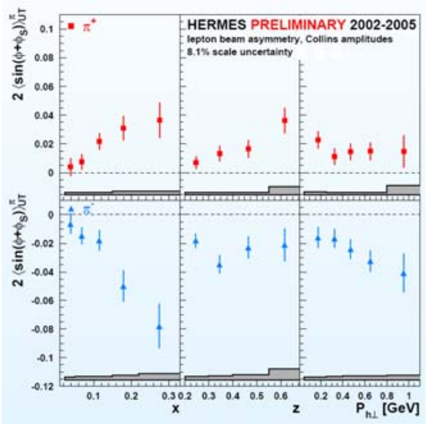
→direct flavour decomposition



→ first signals of GPDs: $J_u + J_d$

→ **see next talk !**

first extraction of δq , spin-orbit structures & OAM



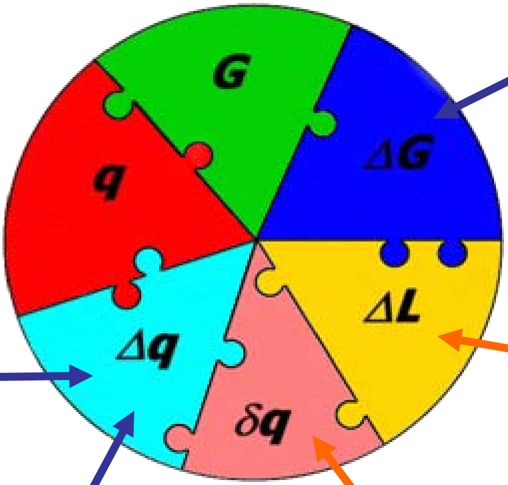
new concepts:

GPDs → 3D picture of the nucleon

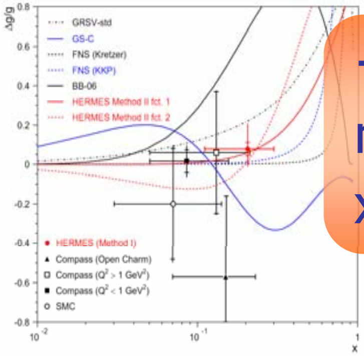
TMDs → beyond collinear approximation

structure of the nucleon

-the open tasks-



first glimpse

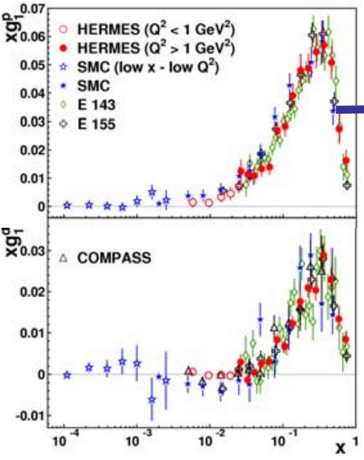


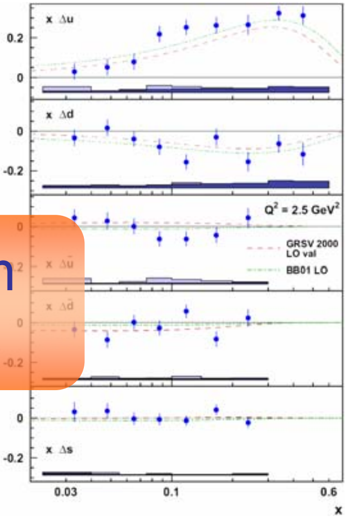
→ detailed measurement of x-dependence

→ first signals of GPDs: $J_u + J_d$

→ **see next talk !**

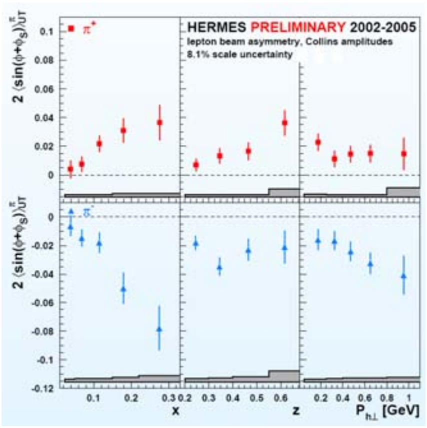
→ detailed measurement in 3 kine variables





→ extrapolation $x \to 0$, $x \to 1$

first extraction of δq

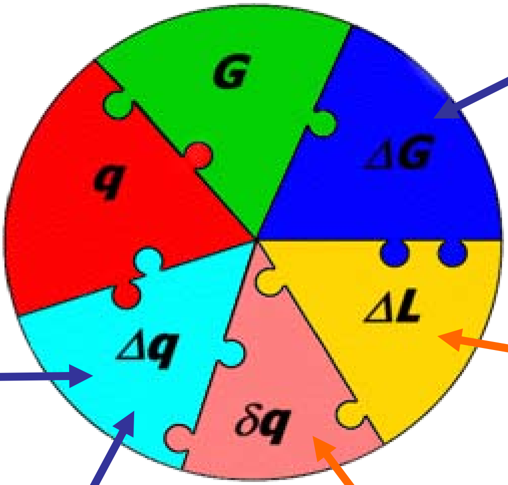


→ detailed measurement in 2 kine variables

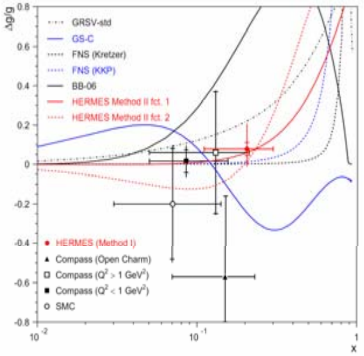
structure of the nucleon

-the future facilities-

RHIC,
EIC,
(JPARC)

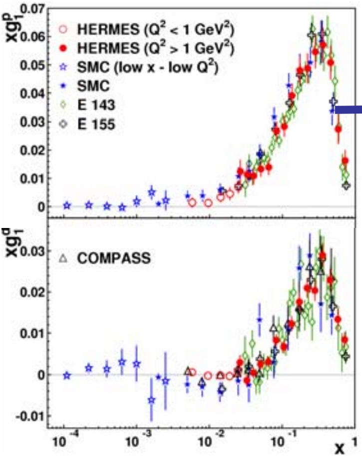


first glimpse

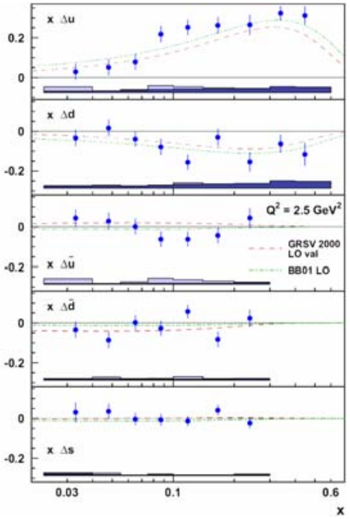


→ first signals of GPDs: $J_u + J_d$

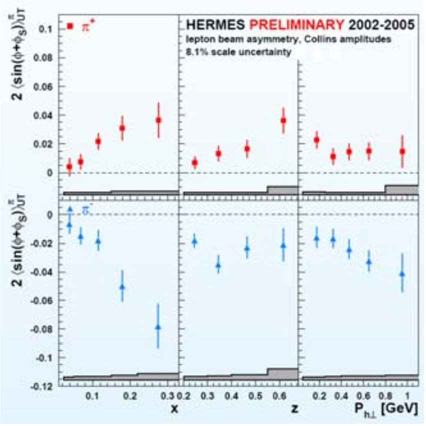
→ **see next talk !**



polarised collider:
EIC



first extraction of δq

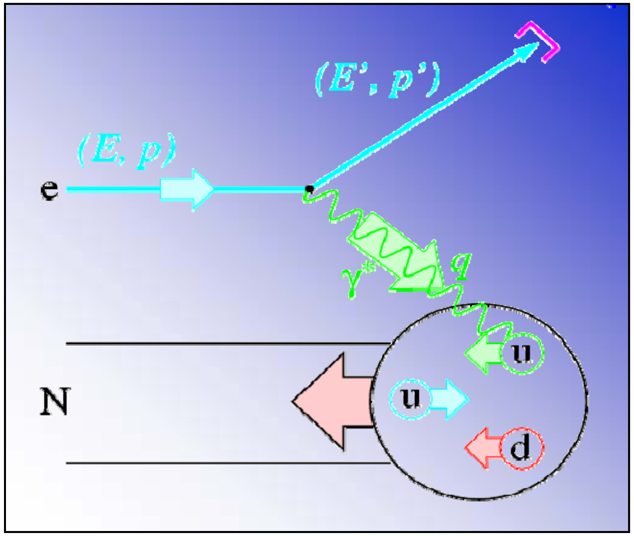


JLab@12GeV
EIC

EIC,
FAIR

Backup slides

polarised *inclusive* DIS



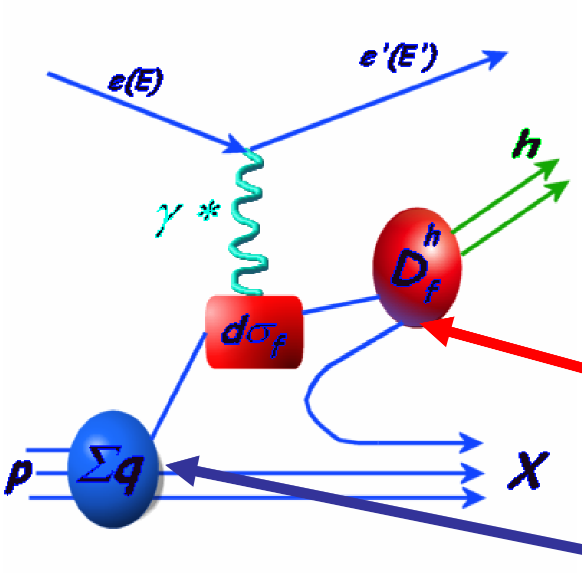
$$\sigma\,(\mathrm{ep} \rightarrow \mathrm{e'X})$$

$$\frac{d^2\sigma}{d\Omega dE'} \propto L_{\mu\nu}\, W^{\mu\nu}$$

$$W_{\mu\nu} = -g^{\mu\nu}\, F_1(x, Q^2) + \frac{p^\mu p^\nu}{\nu}\, F_2(x, Q^2)$$
$$+ i\varepsilon^{\mu\nu\lambda\sigma}\frac{q_\lambda}{\nu}\left(S_\sigma\, g_1(x, Q^2) + \frac{1}{\nu}\left(p\cdot q S_\sigma - S\cdot q p_\sigma\right) g_2(x, Q^2)\right)$$

spin1: $-r_{\mu\nu} b_1(x,Q^2) + \frac{1}{6}(\ldots) b_2(x,Q^2) + \ldots$ **often neglected... but:**

polarised *semi*-inclusive DIS



$$\sigma\,(\mathrm{ep} \rightarrow \mathrm{e}'\,h\,\mathrm{X})$$

distribution function

fragmentation function

$$\mathrm{d}\Delta\sigma^{\mathrm{h}}(z) \propto \sum_f \Delta q_f(x) \otimes d\Delta\sigma_f \otimes D_f^{\mathrm{q}\rightarrow\mathrm{h}}(z)$$

'purities' (based on MC tuned to HERMES multiplicities)

$$\vec{A} = P\vec{Q}$$

$$\vec{\mathrm{A}} = \left(A_{1,p/d}, A_{1,p/d}^{\pi^{+/-}}, A_{1,p/d}^{K^{+/-}}\right)$$

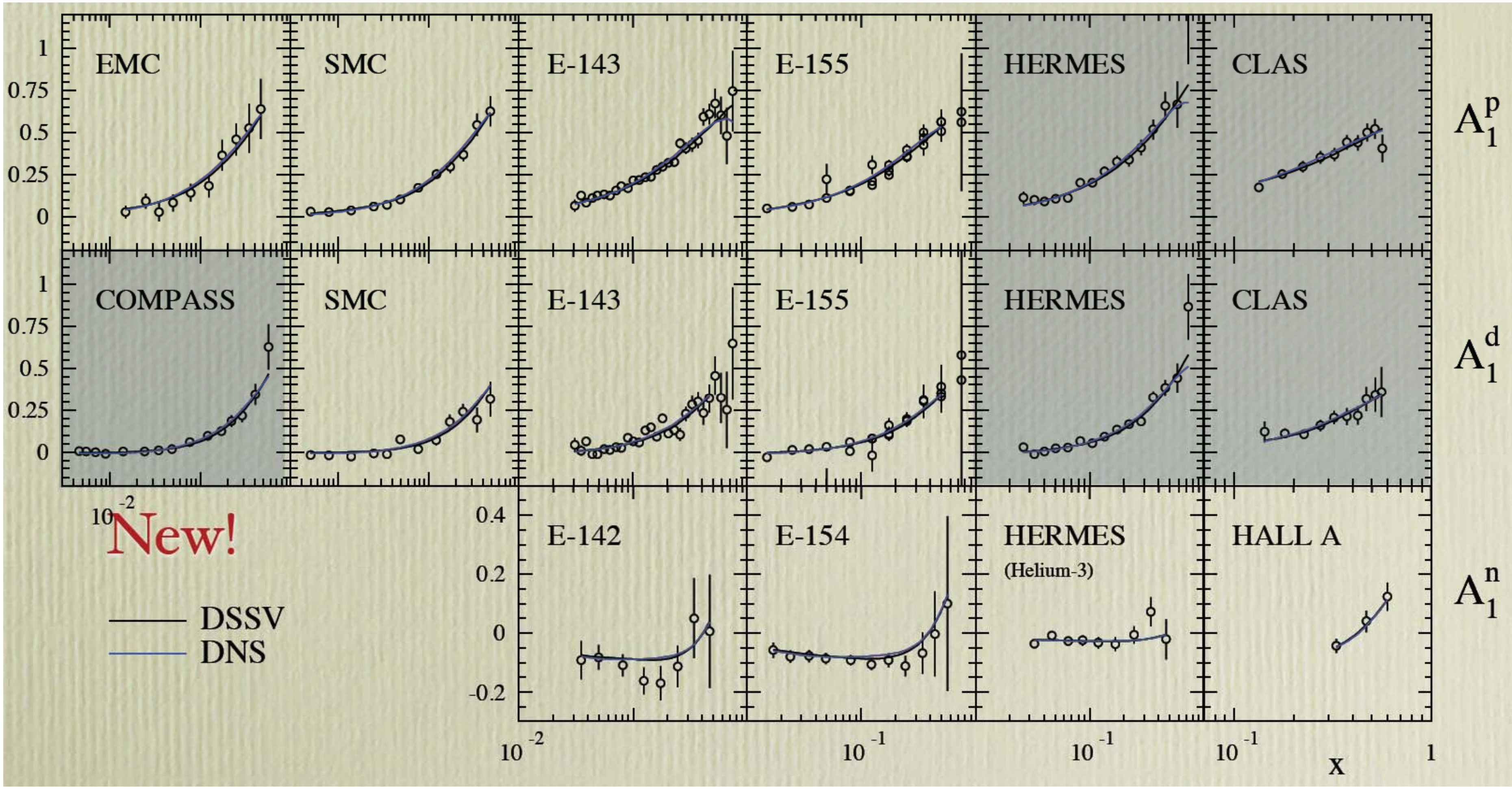
$$\vec{Q} = \left(\frac{\Delta\mathrm{u}}{\mathrm{u}}, \frac{\Delta\mathrm{d}}{\mathrm{d}}, \frac{\Delta\bar{\mathrm{u}}}{\bar{\mathrm{u}}}, \frac{\Delta\bar{\mathrm{d}}}{\bar{\mathrm{d}}}, \frac{\Delta\mathrm{s}}{\mathrm{s}}, \frac{\Delta\bar{\mathrm{s}}}{\bar{\mathrm{s}}} = 0\right)$$

NLO fit to DIS+SIDIS data

good old & new DIS data:

[R. Sassot: EIC-Hampton08 workshop]

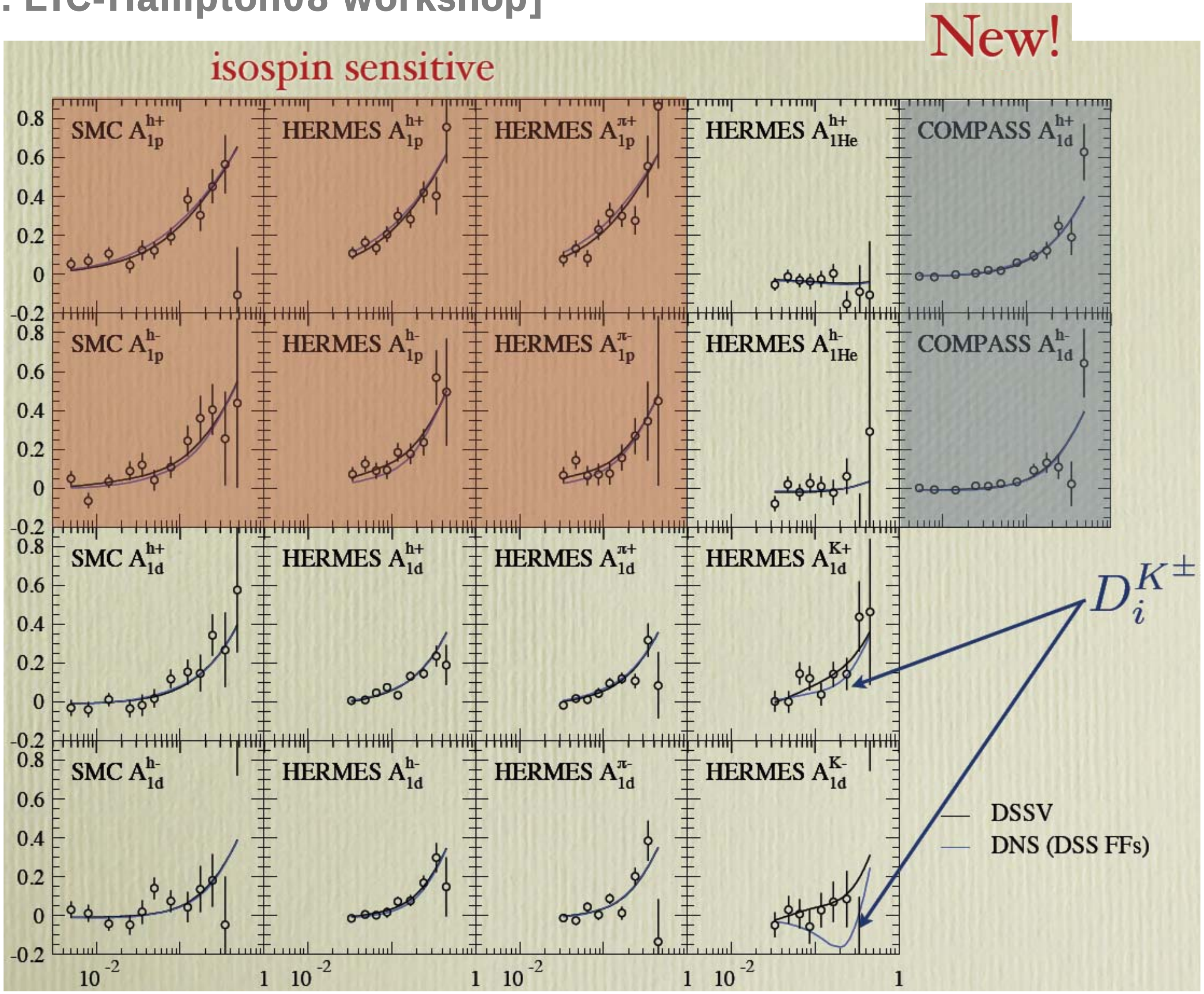
New!



NLO fit to DIS+SIDIS data

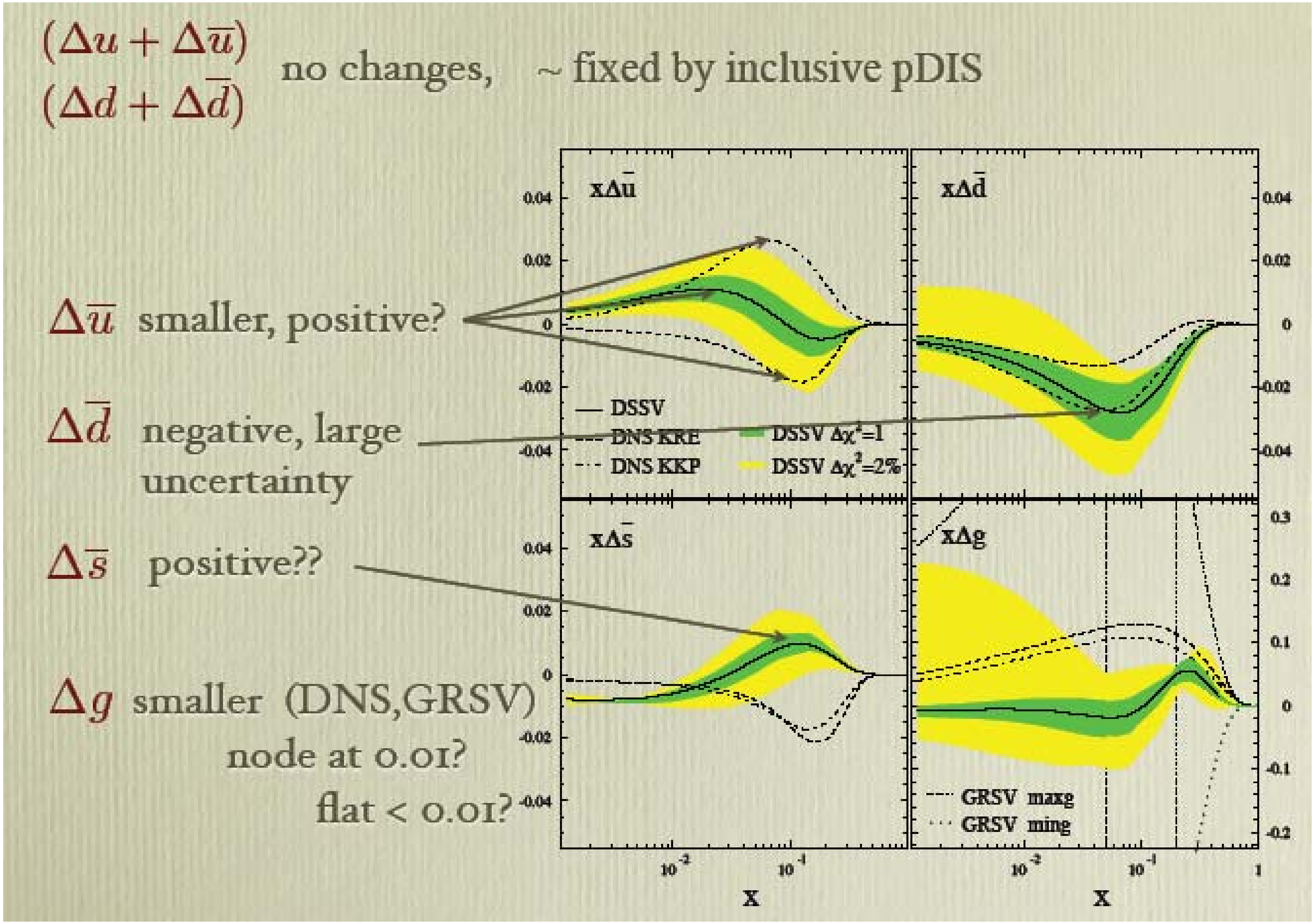
good old & new SIDIS data:

[R. Sassot: EIC-Hampton08 workshop]



NLO fit to DIS+SIDIS data

DSSV **[R. Sassot: EIC-Hampton08 workshop]**



$(\Delta u + \Delta\bar{u})$
$(\Delta d + \Delta\bar{d})$ no changes, ~ fixed by inclusive pDIS

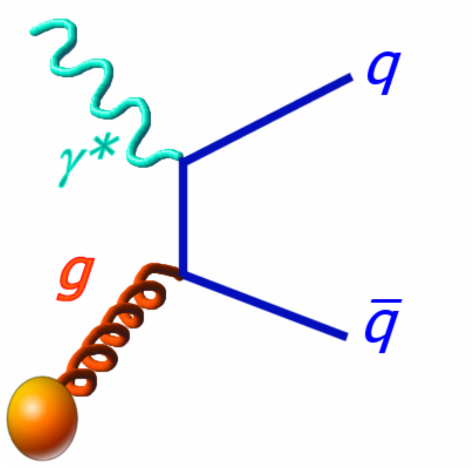
$\Delta\bar{u}$ smaller, positive?

$\Delta\bar{d}$ negative, large uncertainty

$\Delta\bar{s}$ positive??

Δg smaller (DNS,GRSV)
node at 0.01?
flat < 0.01?

direct measurement of ΔG



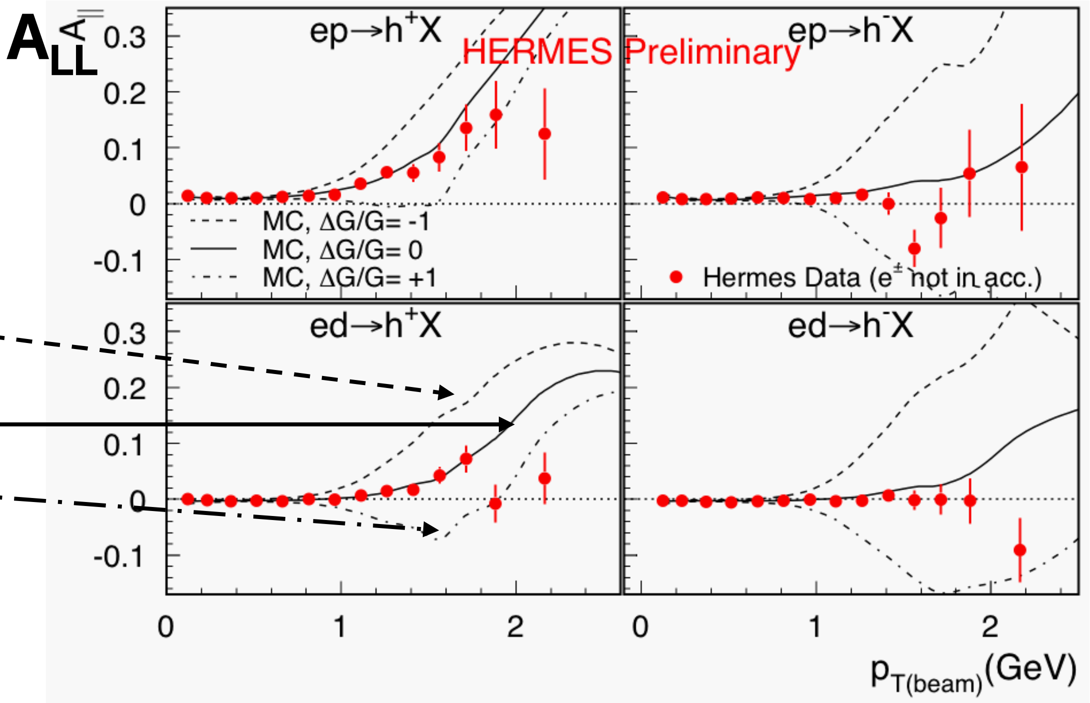
- **golden channel: charm production**

  → theoretically very clean

  → experimentally very challenging

- @HERMES (√s=7 GeV):

  hadron production at high P_T



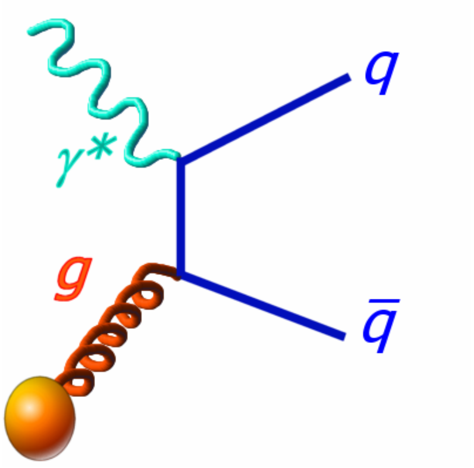
$^{\text{Pythia}}$MC:

$\Delta g/g = -1$

$\Delta g/g = 0$

$\Delta g/g = +1$

direct measurement of ΔG



- **golden channel: charm production**
- @HERMES: hadron production at high P_T

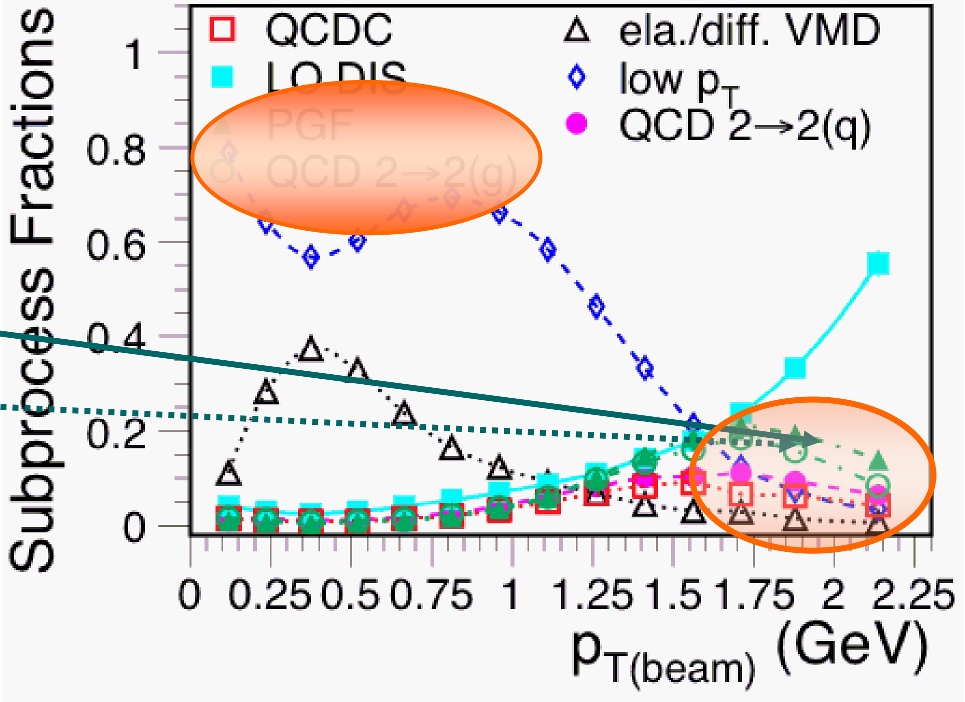
$ed \to h^{\pm}X$: direct, resolved, soft processes

[Pythia MC]

signal processes:

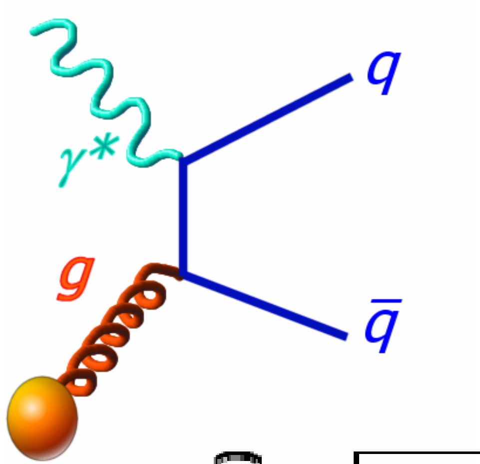
PGF

QCD 2→2(g)



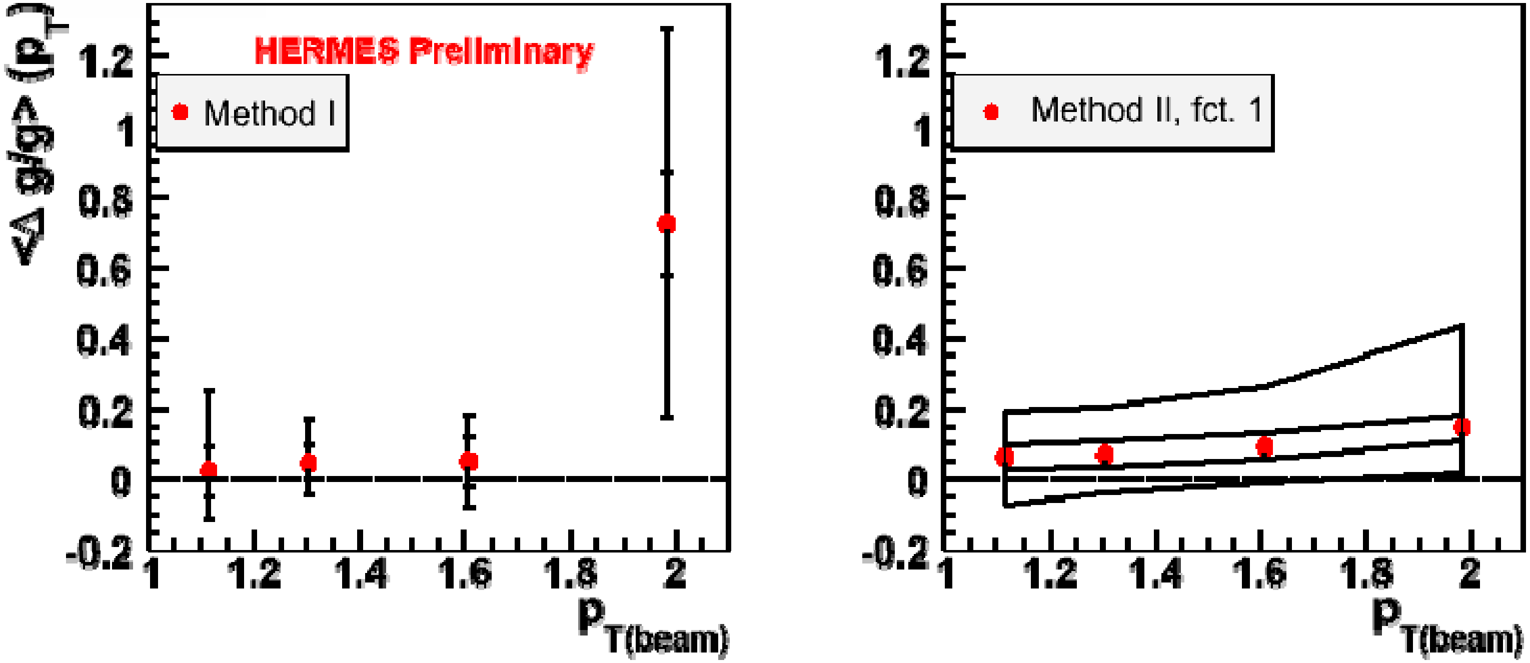
$$A_\parallel = r^{bg} A_\parallel^{bg} + r^{sig} A_\parallel^{sig}$$

direct measurement of ΔG

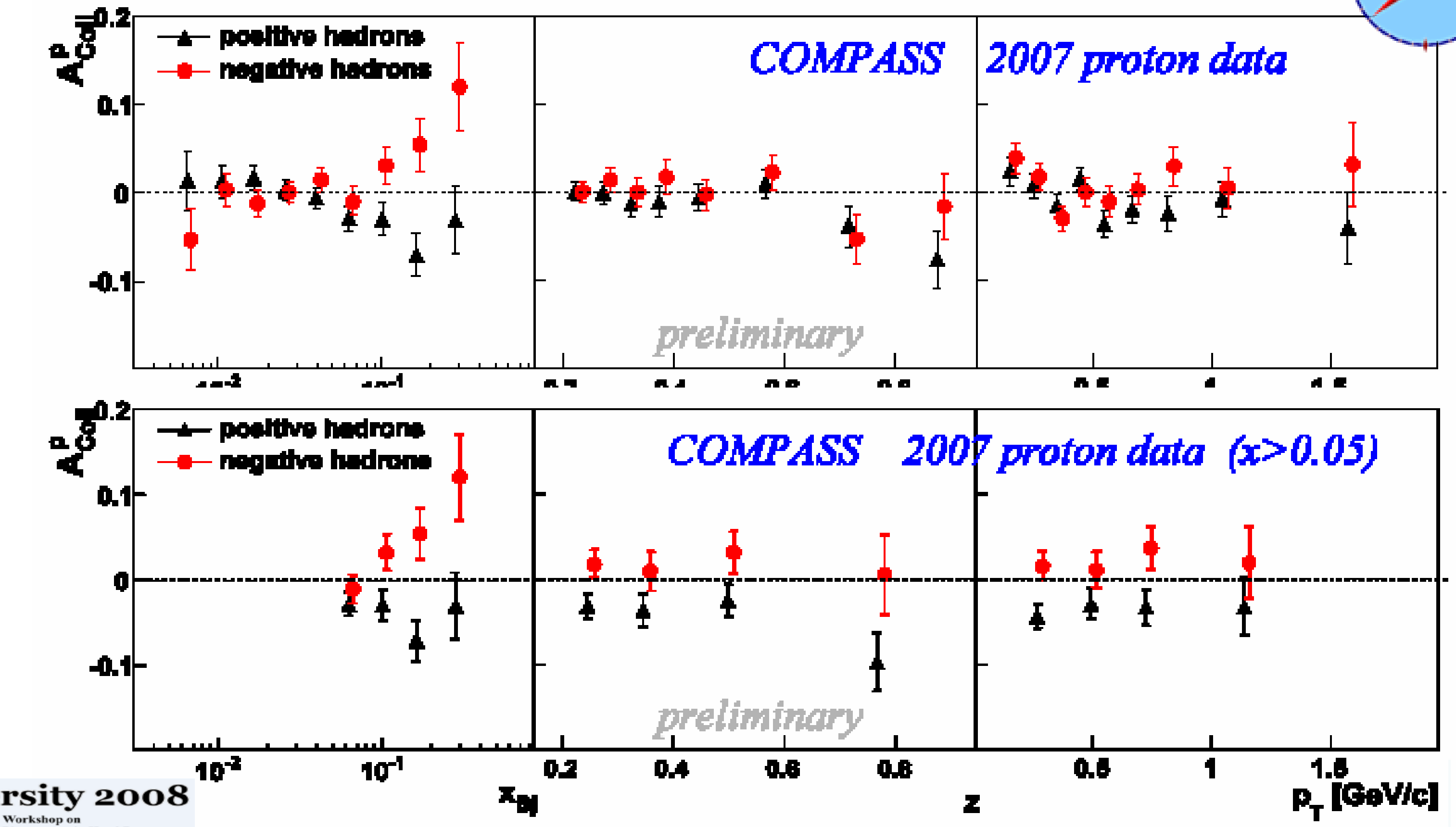


- **golden channel: charm production**
- @HERMES: hadron production at high P_T

$$ed \rightarrow h^{\pm}X$$



Collins asymmetries from proton



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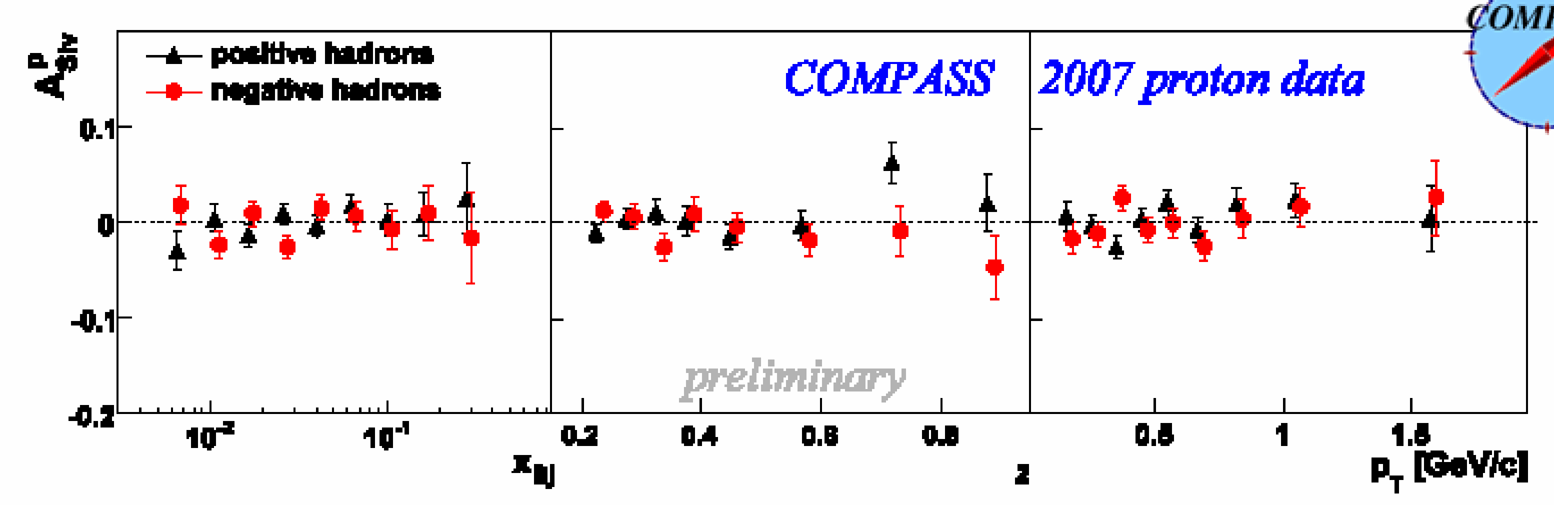
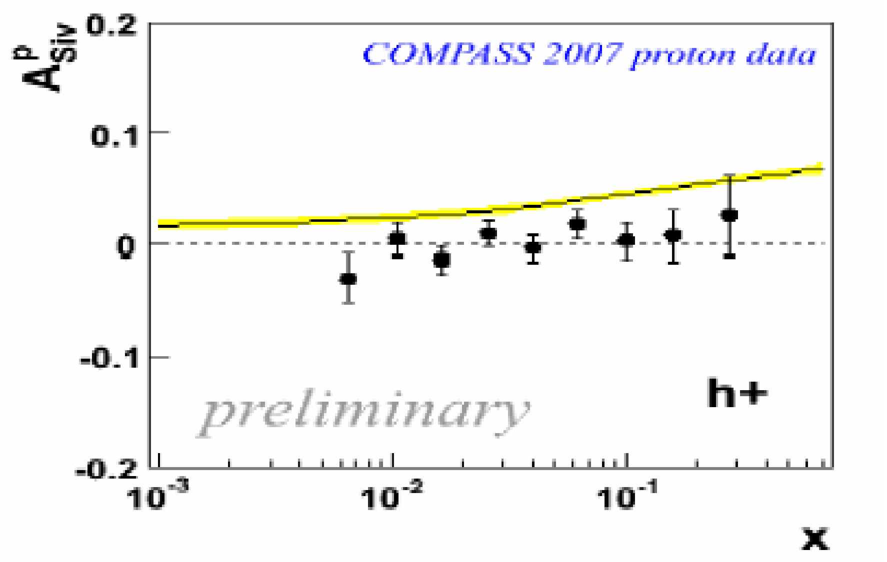
Sivers asymmetries from proton



Asymmetry small, compatible with zero within present statistical errors

- ✓ Unexpected result
- ✓ Of paramount importance



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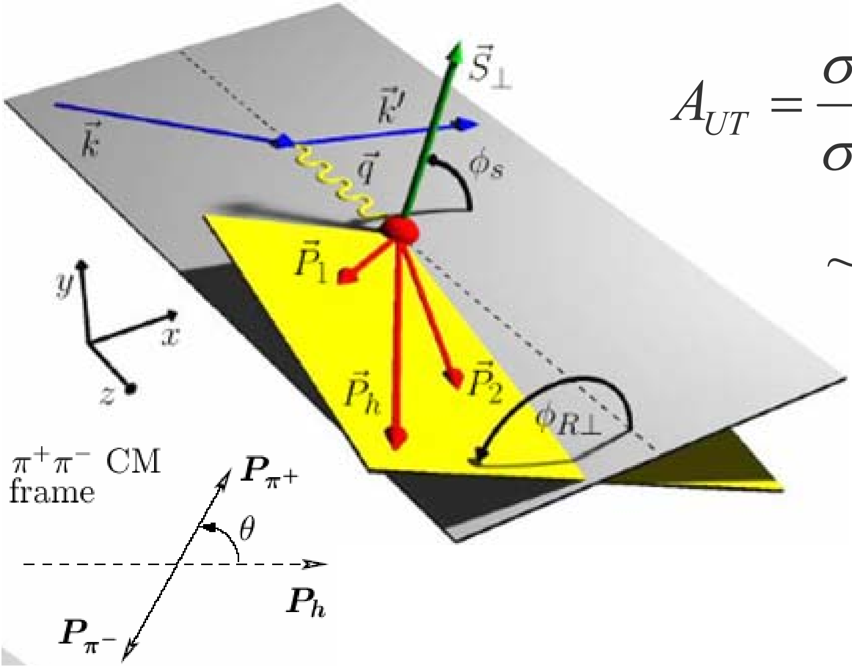
semi-inclusive 2-hadron production

$$e\,p^{\uparrow} \rightarrow e\,\pi^{+}\pi^{-}\,X$$

2-hadron asymmetries



$$A_{UT} = \frac{\sigma^\uparrow - \sigma^\downarrow}{\sigma^\uparrow + \sigma^\downarrow}$$

$$\sim \sin(\phi_{R\perp} + \phi_S)\sin(\theta)\,\delta q(x)\,H_1^{\triangleleft q}(z, M_h^2)$$

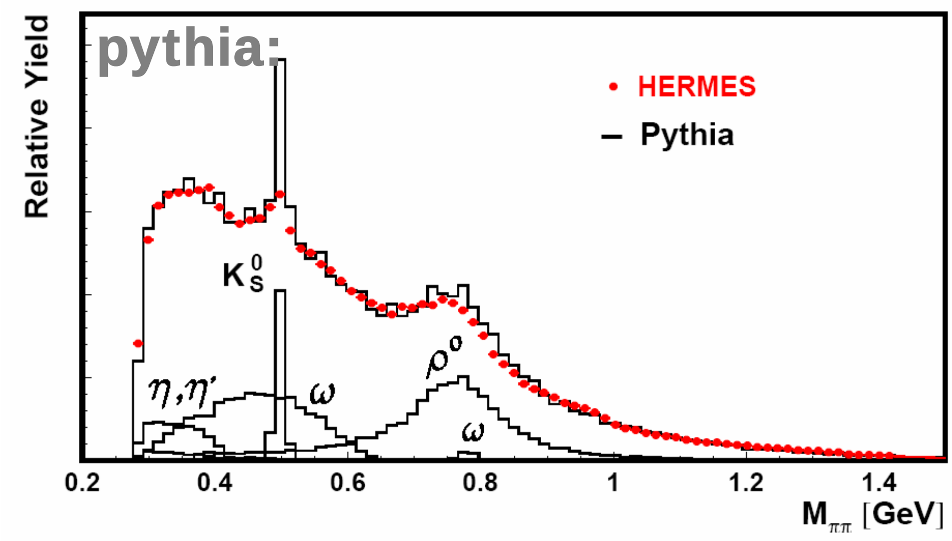
interference fragmentation function
between pions in s-wave and p-wave

- only *relative* momentum of hadron pair relevant

  → integration over transverse momentum of hadron pair simplifies factorisation (collinear!) and Q^2 evolution

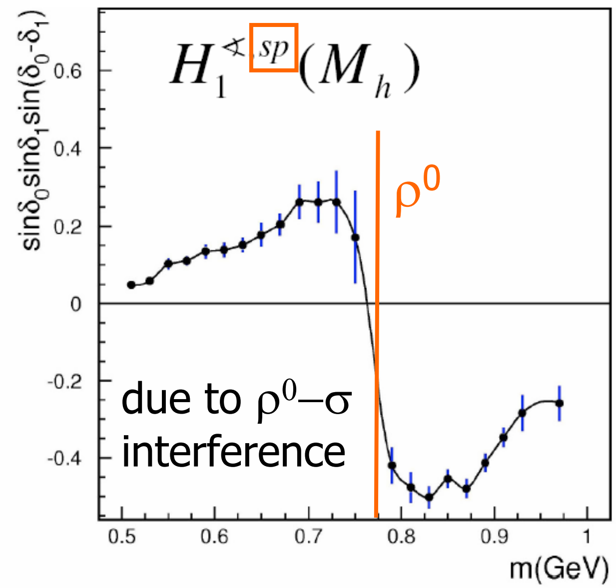
- however cross section becomes very complicated (depends on 9! variables)

models for 2-hadron asymmetries



$$H_1^{\sphericalangle}(z, M_{\pi\pi}^2, \cos\theta) =$$
$$H_1^{\sphericalangle,sp}(z, M_{\pi\pi}^2) + \cos\theta\, H_1^{\sphericalangle,pp}(z, M_{\pi\pi}^2)$$

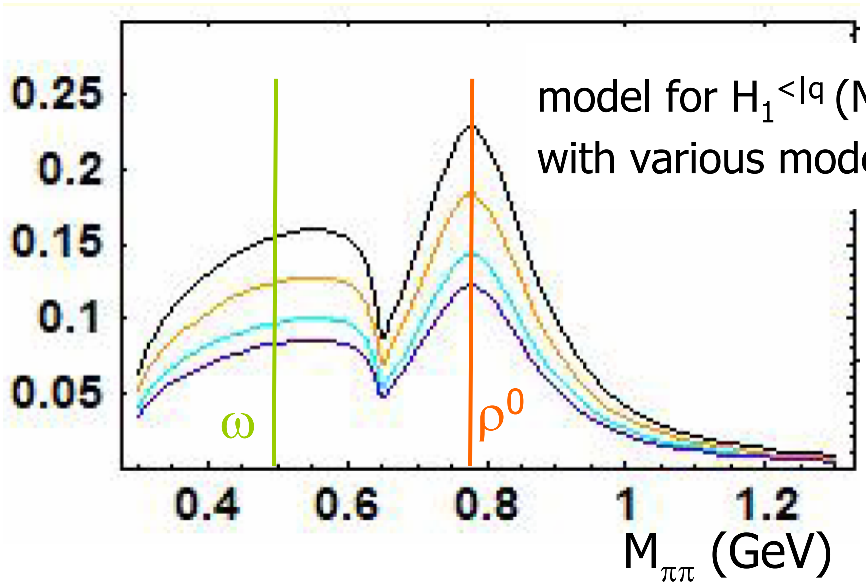
[Jaffe et all, PRL80(1998)]



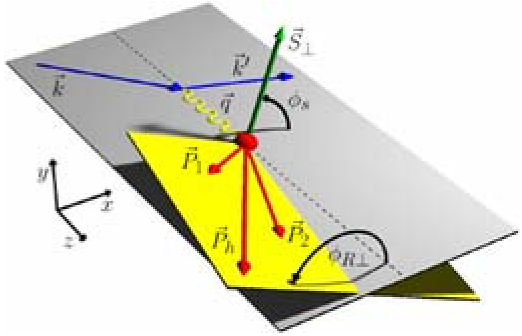
$H_1^{\sphericalangle \boxed{sp}}(M_h)$

due to ρ^0–σ interference

[Bacchetta, Radici PRD74(2006)]



model for $H_1^{<|q}(M_{hh})$ combined with various models for $\delta q(x)$



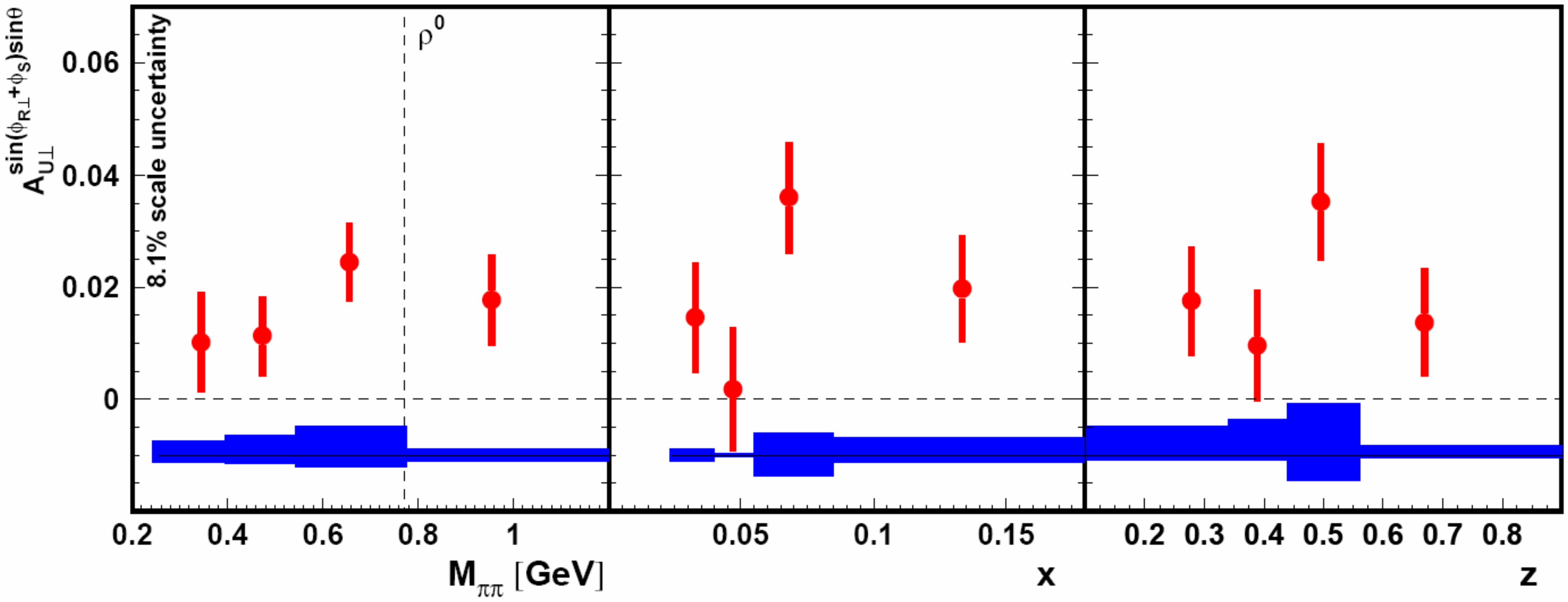
2-hadron asymmetries

$$\delta q(x)\, H_1^{\triangleleft q}(z, M_{\pi\pi})$$

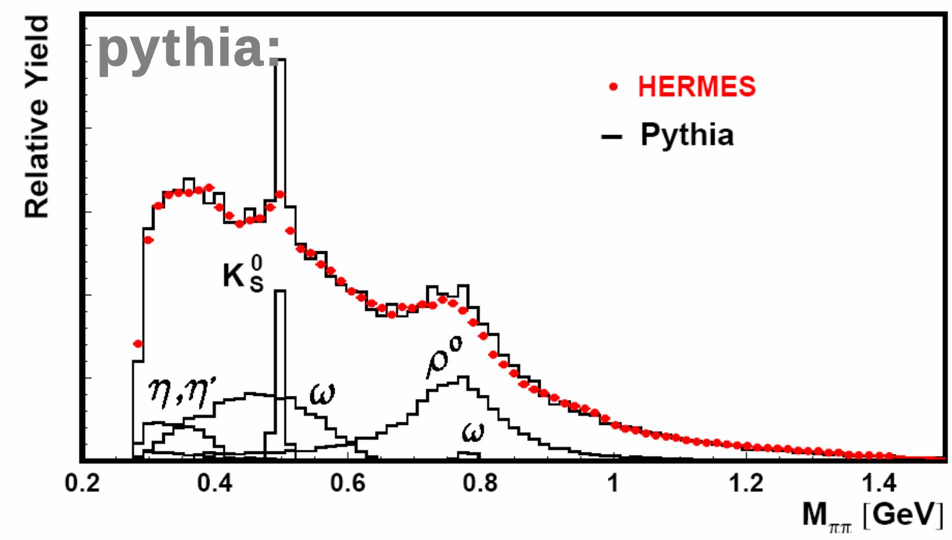
- BOTH: *transversity* and *interference fragmention function* are **non-zero** !

$$e\, p^{\uparrow} \rightarrow e\, \pi^{+}\pi^{-} X$$

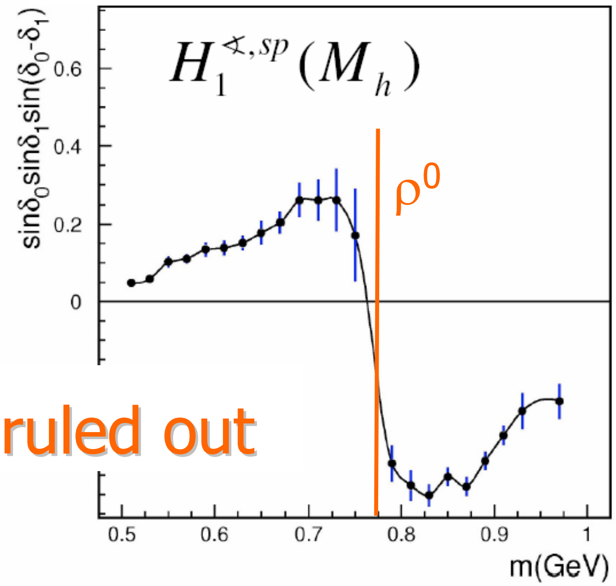
[arXiv:0803.2367]



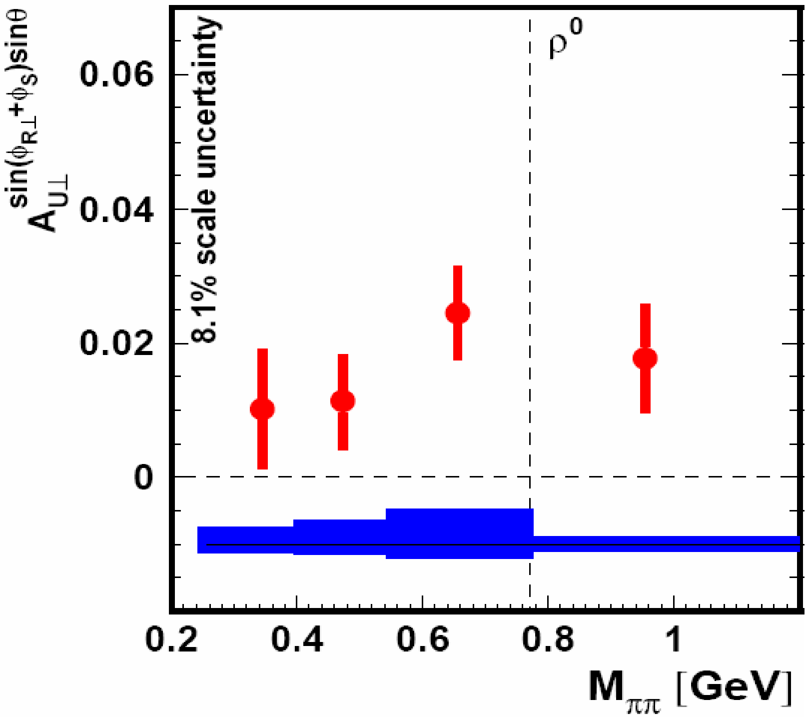
models for 2-hadron asymmetries



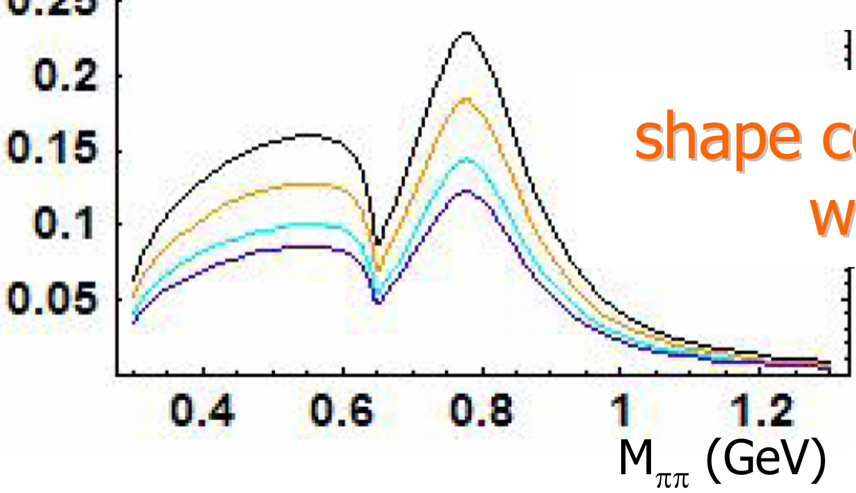
[Jaffe et all, PRL80(1998)]



ruled out

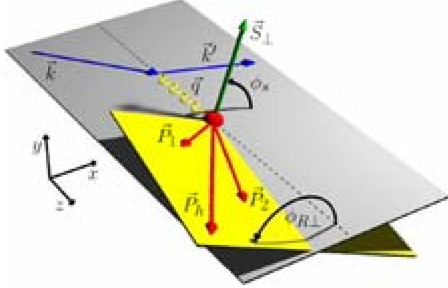


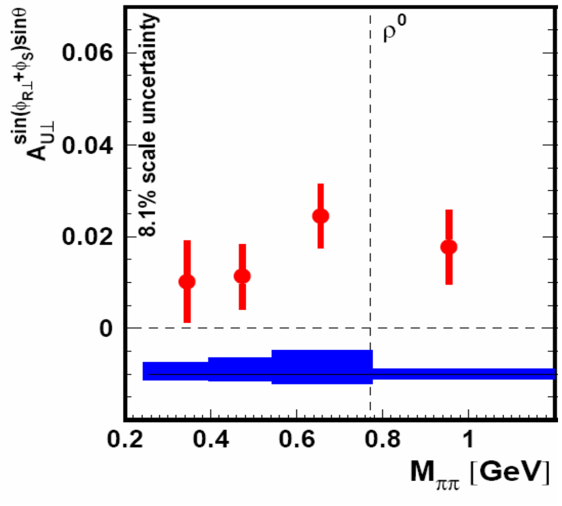
x)



shape compares well

2-hadron asymmetries





$$\sim \delta q(x) H_1^{\triangleleft q}(z, M_{\pi\pi})$$

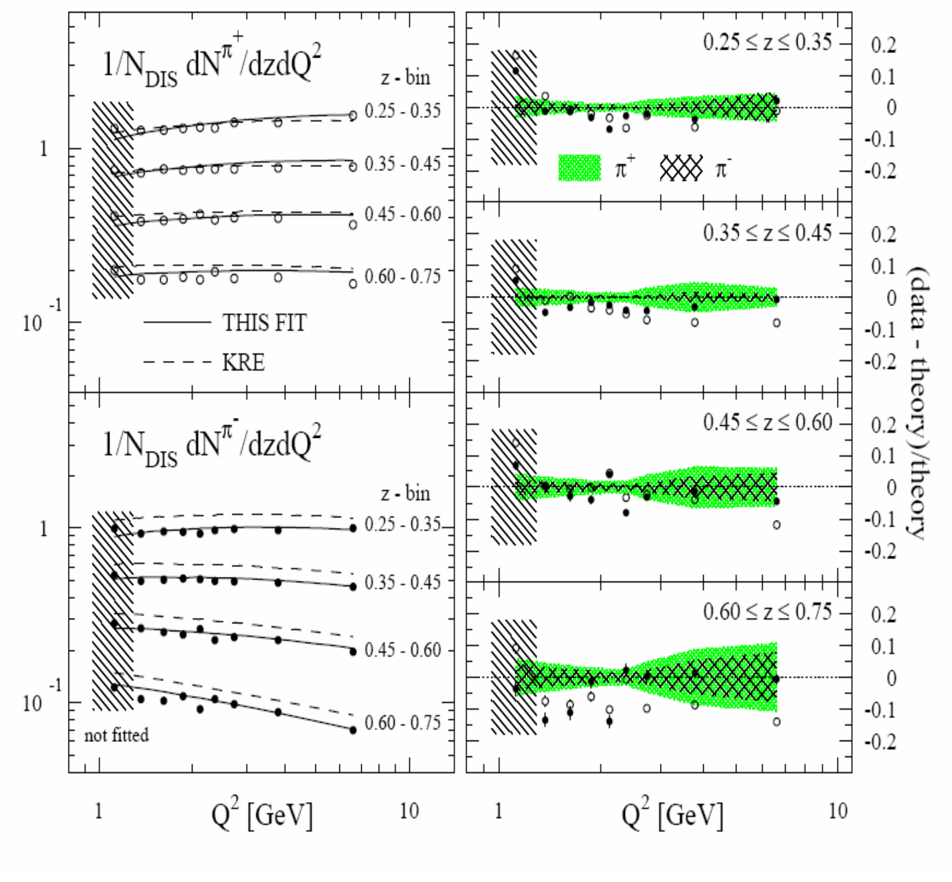
- first evidence for non-zero *interference FF*
- BELLE plans to measure it ! ☺
- this kind of interference effect is a very promising way to access δq @RHIC

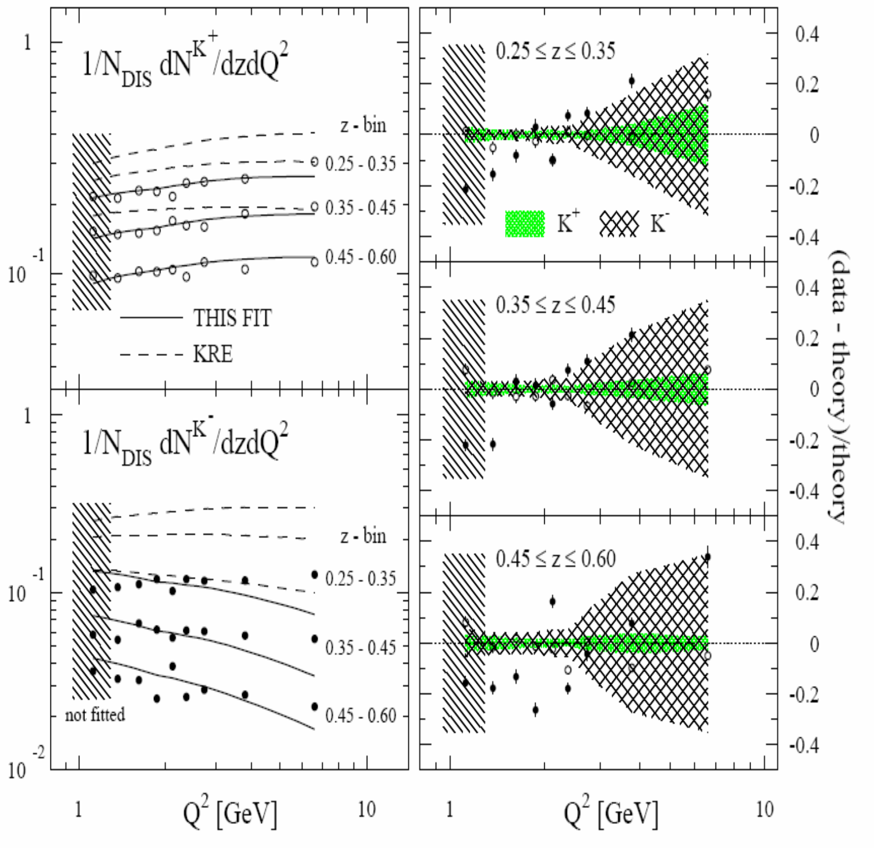
⇒ $\delta q(x)$ from SIDIS + pp + e^+e^-

multiplicities compared to theory

new FF from combined NLO analysis of single-inclusive hadron production in e⁺e⁻, pp and DIS

[deFlorian,Sassot,Stratmann arXiv:0708.0769]





perspectives for GPDs & TMDs

@ new facilities:

- high beam energy (hard regime, wide kinematic range)
- very high luminosity (small xsections, multi-D analyses)
- complete event reconstruction (ensure exclusivity)

→ ideas for accessing GPDs and TMDs @LHC, @GSI, …